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12.—Petrology of the Beaconsfield Conglomerate

By J. E. Glover*

Manuscript accepted—20th May, 1958

The Beaconsfield Conglomerate is made up mainly of pebbles and cobbles, most of which are derived from volcanic rock although quartzite and granite fragments also occur. Some of the more basic volcanic rocks can be matched satisfactorily with dykes (known generally by the field name of quartz dolerite) which intrude the Precambrian basement. Other volcanic rocks are spilitic, but corresponding rocks have not so far been found in the nearby Precambrian basement.

Introduction

The Beaconsfield Conglomerate is a formation in the Yandanooka Group, and is exposed in a syncline between the Mullingarra Inlier and the Darling Fault (see Fig. 1). The sequence in the group, which is of doubtful age (Late Precambrian to Silurian), has been outlined by McWhae *et al.* (1958).

(5)	Mt. Scratch Siltstone	25,000-30,000 ft
(4)	Enokurra Sandstone	680 ft
(3)	Beaconsfield Conglomerate	130 ft
(2)	Arrino Siltstone	1,670 ft
(1)	Arrowsmith Sandstone	1,100 ft

Thicknesses quoted above apply to type sections except in the case of Mt. Scratch Siltstone and the Enokurra Sandstone, where the type sections represent an incomplete thickness.

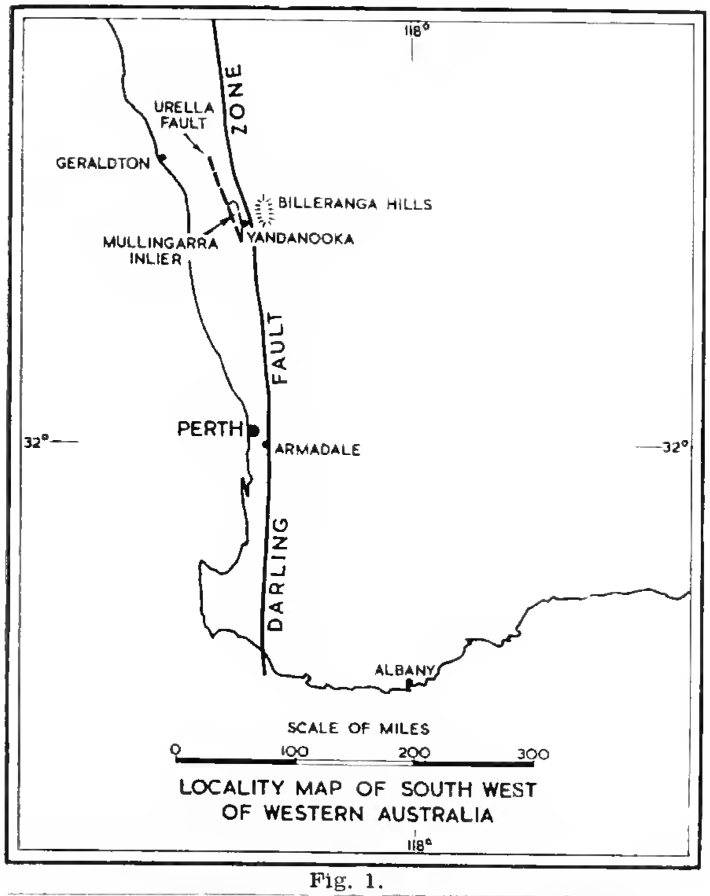

Fig. 1.

The Beaconsfield Conglomerate is made up almost entirely of rounded pebbles and cobbles, most of which consist of volcanic rock.† All other formations in the Yandanooka Group, except the Enokurra Sandstone, contain abundant volcanic detritus, and study of their petrology logically begins with investigation of the Beaconsfield Conglomerate, where the volcanic fragments are largest and most easily identified. This paper discusses the petrography and petrology of 14 specimens from the conglomerate: twelve (36919, 38714-38722 incl., 38729, 39645) were collected by the author from an outcrop approximately 300 yards north of Granite Hill Trig., about 2 miles east-south-east of Yandanooka. Samples 32264 and Pf11 †† were kindly made available for description by the Geology Department and West Australian Petroleum Pty. Ltd., respectively. All specimen numbers, with the exception of Pf11, are those of the Geology Department of the University of Western Australia.

Petrography

General

Most specimens described here consist of individual pebbles and cobbles, and are usually stained red-brown from weathering. Many specimens are highly carbonated, and a few contain two or more pebbles cemented together by calcite. Six rock types can be recognised, namely:

(i) Spilitic lavas,
(ii) Quartz micro-diorites,
(iii) Transitional volcanic rocks,
(iv) Sandstone,
(v) Granitic fragments,
(vi) Quartzite.

Quartzite pebbles are mentioned by McWhae *et al.* (1958) and have been seen in the field by the present author, but are not described here. The other rocks are described under separate headings below.

Spilitic lavas

Four pebbles (specimens 36918, 38714, 38720, 38721) consist of porphyritic volcanic rock. Specimen 38721 (Fig. 2) is the least weathered and has been studied in most detail. It contains euhedral phenocrysts of sodic plagioclase, generally about 0.6 mm long in a fine-grained groundmass of minute plagioclase laths (mostly about 0.05 mm long), ilmenite and limonite granules and patches, and minor chlorite, epidote

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† The term volcanic rock is used to denote extrusive rocks and their intrusive equivalents where these cannot be distinguished.

†† Specimen number assigned by West Australian Petroleum Pty. Ltd.

and quartz. Irregularly shaped patches of calcite, chlorite and quartz are scattered throughout and seem to have filled vesicles. Some of the quartz contains minute apatite needles. Specimens 36918, 38714 and 38720 are similar, but amygdales of chlorite are more prominent, and rutile is a common accessory.

Fig. 2.—Spilitic lava (specimen 38721) showing phenocrysts of sodic plagioclase in a fine-grained groundmass of minute plagioclase grains and abundant iron ore. Amygdales consist of calcite (lower left), intergrown quartz and chlorite (centre right) and quartz. Diameter of field, 2 mm.

Plagioclase phenocrysts in specimen 38721 have a poorly developed preferred orientation, are altered locally to calcite and chlorite, and less commonly, to clay minerals and epidote. Where (001) cleavage is visible, extinction angles in sections perpendicular to a are negative, and the plagioclase is therefore more sodic than intermediate oligoclase. Optical data from four grains investigated with the universal stage depart notably from curves based on the standard data of Duparc, Reinhard and Nikitin, presented by Turner (1947). When several curves are used to check the composition of a grain, estimates from the various curves are likely to vary considerably (by up to 10%). Average composition of the plagioclase suggested by approximation from the curves is in the albite range. $2V_\gamma$ for three of the grains is 88° (measured in one subindividual), 88°, 89° (two subindividuals), 90°, 90°, 92° (three subindividuals). Cloudiness of phenocrysts from alteration hinders precise determination of refractive indices, but the most common value for N_β is 1.537 ± .001, indicating An_{15} — An_{19} (Winchell, 1946, p. 338). Readings as low as 1.532 ± .001 (An_7 — An_{11}) have been noted for a few grains, but in general the composition indicated from refractive indices is more calcic than that indicated by universal-stage methods. Faint normal zoning can be seen in a few phenocrysts but it is nowhere important.

Measurements with the universal-stage were made, as far as possible, on unaltered patches in the grains. Experimental error seems inadequate to explain completely the discrepancies between optical data and the curves presented by Turner. The discrepancies probably arise partly from the method of construction of the standard curves, as according to Köhler (1949, p. 593), they were based on the optics of plutonic (low temperature) plagioclases, and do not apply closely to plagioclase from volcanic rocks. There seem, moreover, to be compositional differences between adjacent lamellae in some plagioclase grains, as observed elsewhere by Bradley (1953, p. 228) and others. It is proposed only to note the anomalies and their probable causes here, for the weathering and deuteric alteration of the rocks prevents presentation of precise chemical and optical data.

Similar anomalous optics and the same range in 2V were noted in five carefully measured phenocrysts from specimens 36918, 38714, and 38720. The composition of all the phenocrysts is, therefore, thought to be comparable, and from the refractive index determinations in specimen 38721 it lies mainly in the range of sodic oligoclase. Carlsbad, albite, Carlsbad-albite and pericline twins are present in phenocrysts in all specimens, and one occurrence of either the Manebach-Acline or the optically indistinguishable Ala A law, was observed in specimen 38720. Phenocrysts with numerous subindividuals are not common, and many grains contain only three or four subindividuals: a few with Carlsbad twins show only two. It is not unusual for two phenocrysts to form penetration twins.

The porphyritic texture, rough flow banding of phenocrysts and presence of amygdales strongly indicate extrusive origin. The rocks are referred to as spilitic lavas from their association of sodic oligoclase phenocrysts with an iron-rich groundmass.

Quartz micro-diorites

Five specimens (32264, 38717, 38718, 38722, 38724) represent the quartz diorite suite. Specimen 38718 (Fig. 3A) illustrates their mineralogy and texture. It is a weathered, even-grained to slightly porphyritic, holocrystalline hypabyssal or extrusive rock, with an average grain-size of less than 1 mm. It contains plagioclase laths, aggregates of ilmenite, limonite and haematite, clots of yellow-green chlorite, patches and veins of calcite and minor epidote. Interstitial quartz is fairly abundant, and together with K-feldspar, probably represents the end stage of crystallization. Both quartz and K-feldspar are penetrated by numerous colourless rods and needles of apatite. Plagioclase laths are generally about 0.5 mm long, have no obvious preferred orientation, and are mostly twinned on the Carlsbad, albite, and Carlsbad-albite laws. Almost all grains are at least partly altered to sericite, chlorite and calcite. The core of one of the larger and hence most calcic grains was estimated as An_{34} from standard curves, and $2V_\gamma = 73°$. Most plagioclase shows normal zoning from andesine to calcic oligoclase, and many smaller grains contain needles of apatite. Some plagioclase is partly ringed by pale brown, kaolinized K-feldspar, which separates it from patches of interstitial quartz. A little of the black iron ore is likely to be primary, but many aggregates of

chlorite, limonite and black iron ore have almost certainly replaced other ferromagnesian minerals, partly by pneumatolysis and partly during weathering. These aggregates are penetrated in ophitic and sub-ophitic fashion by plagioclase.

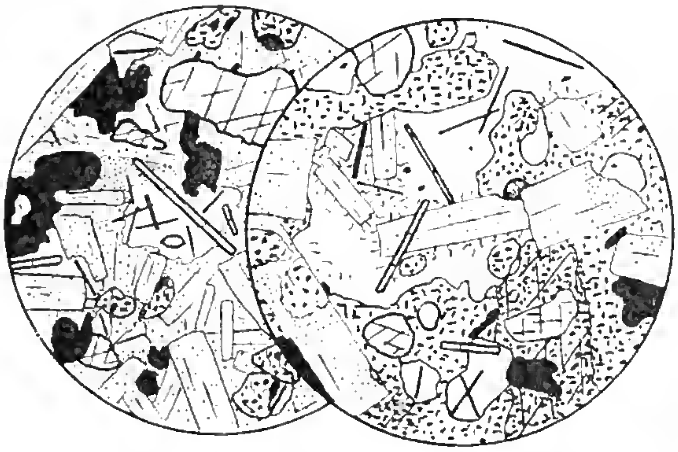

Fig. 3 (A).—Quartz micro-diorite (specimen 38718) showing iron ore (black), plagioclase (lightly stippled), chlorite (heavily stippled), K-feldspar (closely stippled), calcite (with narrow intersecting twin lamellae) and quartz (colourless). Apatite is present as rods and needles. Diameter of field, 2 mm.

(B.).—Dyke rock from Billeranga Hills (specimen 39644) showing iron ore (black), plagioclase (stippled), chlorite (heavily stippled), and calcite (with narrow intersecting twin lamellae). At lower right, amphibole (heavily stippled, with cleavage) contains a core of augite. Note also the epidote grain at right centre with high relief, the apatite rods, and the micrographic texture of some quartz. Diameter of field, 2 mm.

It is not known whether the rock is hypabyssal or extrusive, and it is therefore named only from its mineralogy, texture and grain-size. Changes caused by pneumatolysis and weathering present additional difficulty in classification. According to the classification of Hatch, Wells and Wells (1956), the rock can be regarded as transitional between quartz micro-gabbro and quartz micro-diorite.

Specimens 38717, 38722, 38724 are similar mineralogically and texturally, but their plagioclase is generally more sodic, and ranges from sodic andesine to sodic oligoclase. Specimen 32264 is porphyritic with apparent flow alignment of andesine phenocrysts and amygdales of calcite and chlorite. It has been described by Baker (1951, pp. 60-62) as an andesite (i.e. a fine-grained micro-diorite).

It is appropriate here to compare the above rocks with the basic dyke rocks which transect basement in the area. Specimen 39644 (Fig. 3B) is from a dyke cutting the Billeranga Beds near the 1,223 ft Trig. Station (about 20 miles due east of Yandanooka). The fresh rock is dark grey-green with subophitic texture, and contains pyroxene, plagioclase laths, skeletal black iron ore, abundant quartz and minor pyrite, epidote and K-feldspar. Pyroxene is pale brown with $2V_\gamma$ close to 56° and $Z\wedge c$ about 44°, and has green chlorite, green-brown hornblende, tremolite and, locally, biotite moulded on it. Measurement of the core of one plagioclase grain indicated An_{36} from standard curves, and $2V_\gamma$ = 88°. Plagioclase is commonly zoned from andesine to oligoclase. Some grains are water clear, but many are converted almost wholly to sericitic aggregates. K-feldspar and quartz have micrographic texture in many places, are locally penetrated by acicular tremolite and contain abundant apatite rods and needles, some up to 2 mm long. Granules of epidote are scattered throughout. Texture and mineralogy therefore indicate quartz micro-diorite.

The five weathered pebbles from the Beaconsfield Conglomerate described above resemble strongly the rocks from the intrusive, and it is reasonable to assume that they were comagmatic.

Transitional volcanic rocks

Four specimens (Pf 11, 38715, 38719, 39645) contain highly sodic plagioclase but are different texturally from the spilitic lavas described above. Specimen 39645 is an amygdaloidal porphyritic and spilitic rock with phenocrysts of sodic oligoclase in a groundmass coarser than that of the spilitic lavas. The groundmass contains abundant pale green chlorite, minute plagioclase laths, iron ore granules and quartz. Specimen Pf 11, although porphyritic and spilitic, also has a coarser grained groundmass than the spilitic lavas. Specimens 38715, 38719 are even-grained to slightly porphyritic and their texture resembles that of most of the pebbles of micro-diorite. They are in places converted almost entirely to carbonate, but most of their plagioclase, where relatively unaltered, is clearly more sodic than that of the more typical micro-diorites, and approaches in composition that of the spilites.

Sandstone

Specimen 38716 is a sandstone consisting mainly of well-sorted, highly angular to moderately well-rounded quartz grains in a finely divided, pale brown matrix (see Fig 4). Most quartz grains range in diameter between

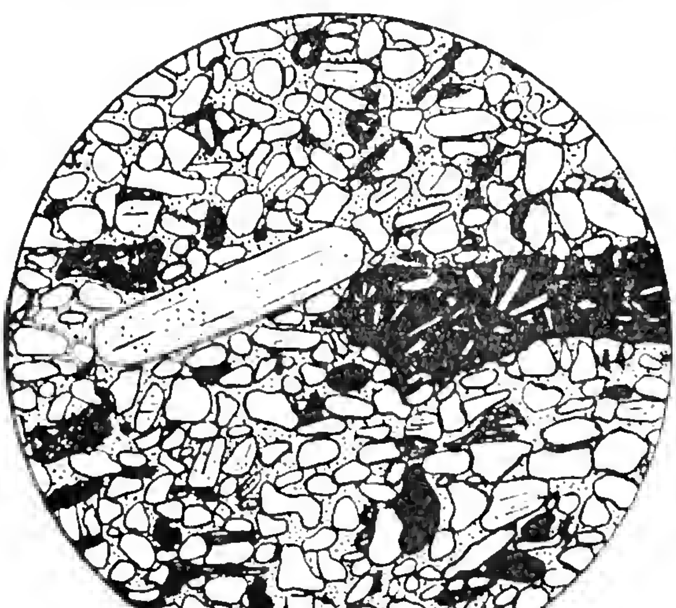

Fig. 4.—Sandstone (specimen 38716) showing feldspar grains (stippled, with cleavage), volcanic fragments (dark) and quartz grains (clear) in an abundant matrix. Diameter of field, 2 mm.

0.05 and 0.1 mm: a few have ragged boundaries where corroded by the matrix. Numerous rutile needles are evident in some quartz grains. Other important constituents of the sandstone are irregularly shaped, red-brown, volcanic fragments; fresh, clear oligoclase; microcline and microcline micro-perthite; and cloudy, kaolinized orthoclase. Incipient crystals and devitrified shards can be identified in many volcanic fragments which are assumed therefore to be of tuffaceous origin. Some volcanic fragments contain minute micro-phenocrysts of feldspar in a brown, iron-stained groundmass, and these fragments may have been derived from flows. Other red-brown opaque grains, some well-rounded, may also be volcanic, but their origin is uncertain. Most of the matrix is opaque and brown from iron staining, but where translucent it consists of pale brown felsic material, part of which may be fine ash. Indeterminate, elongate, cryptocrystalline fragments in the matrix have been tentatively identified as devitrified glass shards. Minor constituents include muscovite, garnet and composite quartz-chlorite grains.

Approximate composition of the sandstone is:

	%
Quartz	37
Volcanic fragments	15
Feldspar	10
Matrix	37
Other minerals	1

Precise classification of the sandstone is not possible. It has been derived from a terrain containing granitic and meta-sedimentary rocks, tuffs, and probably flows. If the abundant matrix contains altered ashy material from contemporaneous pyroclastic activity, the rock is a tuffaceous sandstone: otherwise it should be classified, following Pettijohn (1957, p. 291) as lithic greywacke.

Granitic fragments

Coarse angular fragments of quartz, microcline and microcline micro-perthite are present in the cacite matrix cementing volcanic pebbles in specimen 38714.

Origin of the Beaconsfield Conglomerate

The Beaconsfield Conglomerate is underlain by a thick sequence of fine-grained sediments containing epiclastic volcanic detritus (the Arrino Siltstone), and the abrupt change to conglomerate may have followed sudden elevation of the area being eroded. That area, at the time of Beaconsfield deposition, consisted mainly of volcanic rocks, with subordinate granitic and sedimentary rocks. It is likely, in view of the considerable extent and thickness of the Beaconsfield Conglomerate, that most of the volcanic rocks were extrusive, and that they formed a wide-spread blanket over the area. Late Precambrian or early Palaeozoic quartz dolerite intrusives have been widely recognised in sediments in the Perth Basin, and in exposures of basement rock in its northern part, but no rocks from the flows presumed to have been fed by the intrusives have so far been recognised. The dyke rock from the Billeranga Hills discussed in this paper is more sodic than the quartz dolerites, and extrusives of the more sodic suite may be represented by some of the pebbles and cobbles (quartz micro-diorites) in the Beaconsfield Conglomerate. Textures in some of the quartz micro-diorite pebbles are consistent with the hypothesis of extrusive origin.

No representatives of the spilitic rocks have so far been recognized from the Precambrian basement in the area. It is notable that some spilitic pebbles differ texturally from the lavas and range through porphyritic rocks with coarse groundmasses to even-grained rocks whose textures are similar to those of the micro-diorites. There are several possibilities regarding the origin of the spilites. They may have come from a spilitic magma, they may be differentiates of the same parent magma as the micro-diorites, or they may be products of special conditions (such as soda-metasomatism from sea-water or other sources). It is impossible to establish satisfactorily their petrogenetic relationships from such an assemblage of pebbles and cobbles which may have had diverse origins. It may be significant that the Cardup Shale, near Perth, is intruded by basic and spilitic rocks, for the Cardup Shale is considered to be of the same approximate age and in the same tectonic position as the Billeranga Beds. The basic rocks (quartz dolerites) form dykes, and the spilitic rock (chlorite-albite epidiorite) is in the form either of a large sill, or a flow. The epidiorite shows a similar range in texture to the spilitic rocks from the Beaconsfield Conglomerate, for it is locally highly porphyritic, and elsewhere is more or less even-grained. Prider (1941, p. 44) considers that the quartz dolerites belong to a later period of intrusion that the chlorite-albite epidiorite. Little more can be done toward elucidating the origin of the spilites in the Beaconsfield Conglomerate without careful search for comparable rocks in the nearby Precambrian basement.

No adequate detailed explanation can be offered at present for the virtual absence of volcanic material in the overlying Enokurra Sandstone, though it clearly indicates an abrupt and marked change of provenance.

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13.—Temperature Tolerance of the Chiton Clavarizona hirtosa (Blainville)

By Ron Kenny*

Manuscript accepted—1st January, 1958.

The range of temperature within an individual chiton *Clavarizona hirtosa* is shown to be greater than the difference between the mean temperature of the chiton and that of the wet substrate. Experiments show there is no temperature control mechanism. The thermal death point was 43°C, both in sea water and in air, when the temperature was raised at 1°C per 5 min. The animals are shown to be more tolerant of sustained high temperatures in air than in sea-water. The lethal temperature is greater (by approx. 10°C) than temperatures occurring naturally in the chiton's habitat.

A comparison is made between two chiton populations. The effect of desiccation in relation to temperature is noted. The results are compared with similar experiments carried out in England, Bermuda and South Africa.

Introduction

Investigations on littoral ecology on the West Australian coast, undertaken by various people associated with the Department of Zoology, University of W.A., have posed questions concerning the temperature ranges tolerated by littoral molluscs. For the present investigations the chiton *Clavarizona hirtosa* (Blainville) was selected (a) because of its abundance, (b) because preliminary experiments showed that it tolerated the insertion of a thermocouple, and (c) because there has been little previous work of this nature upon chitons.

Only one reference to temperature effects on a chiton, Arey and Crozier (1919) and one to desiccation of a chiton, F. G. C. Evans (1951) have been found. These are discussed later.

* Department of Zoology, University of Queensland

R. G. Evans (1948) summarises previous work on temperature tolerance of molluscs and points out that the "heat-light-desiccation" complex is probably the most critical of local climatic factors. Heilbrunn (1943) states, "Practically all animals and plants are killed at moderate temperatures which are usually only a few degrees above those at which they are accustomed to live normally. Indeed not infrequently heat death occurs in the normal environment." Broekhuysen (1940), although noting that thermal death points of several gastropod species (measured in the laboratory) were never reached in natural conditions, nevertheless recorded that six South African gastropods showed a direct correlation between thermal death-point and the height of zonation of the particular species on the shore. It was also reported by Gowanloch and Hayes (1926) that within one species, animals collected from different tidal levels showed a lethal temperature gradation.

Ecology of *Clavarizona*

The west coast limestone reefs show typically a "visor", an intertidal undercut at approximately mean sea level and a reef platform at about M.L.W. which terminates abruptly at its seaward edge, often with a narrow, raised rim (Fig. 1). An account of the geological structure of these reefs is given by Fairbridge (1950) and tidal data for the region has been analysed by Bennett (1939) and more recently by Hodgkin and Di Lollo (1958).

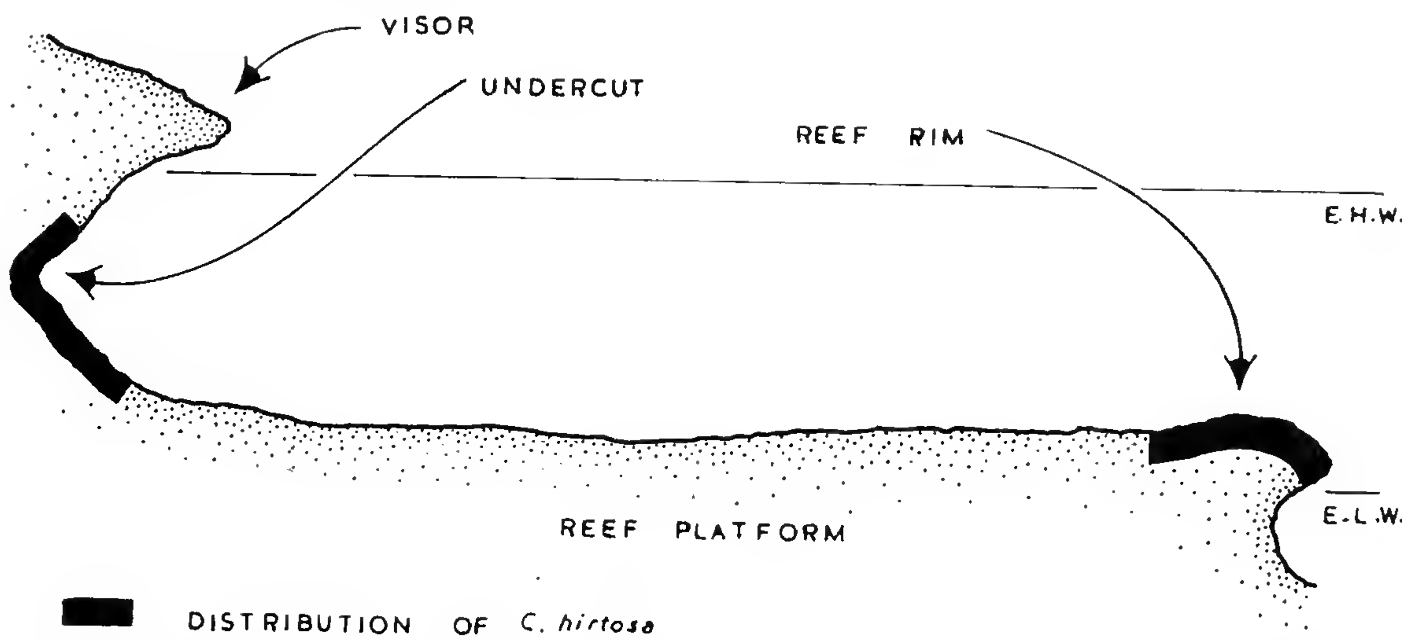

Fig. 1.—Diagram of section through typical limestone reef platform. Vertical scale greatly exaggerated.

Resting chitons are found near the reef rim and on the rock surface in the undercut between tide levels. Where there is no reef platform there is only a single zone of *C. hirtosa* in the undercut.

Although chitons in an undercut may be out of the water for several hours each day, and with low tides and calm weather may be fully exposed to air for the greater part of the day, individuals are generally protected from the full effects of the sun for much of the time by the rock visor.

Individuals situated near the reef rim are rarely exposed to temperature conditions other than those of sea water since, in general, surf conditions are such that even at low tide the reef edge is awash. The reef rim is exposed only when a low sea level, a small tidal range and calm weather coincide. Local tidal and climatic peculiarities are such that the possibilities of these factors summating in the hot and sunny period of a summer day are rare.

Clavarizona hirtosa has been recorded (Hull 1922) on the West Australian coast from Pt. Cloates (22°35' S, 113°50' E) to Eyre (32°15' S, 126°15' E), ranging from tropical to warm temperate climates. The mean maximum air temperature at Carnarvon (25°0' S, 113°50' E) in February is 31.5°C and the mean minimum air temperature at Albany (35°0' S, 118°0' E) in July is 7.5°C; extreme summer maximum air temperatures above 40.0°C have been recorded from Carnarvon and Perth (31°55' S, 115°50' E) and extreme winter minimum air temperatures at Albany approach freezing point.† Water temperatures in this area vary from a summer monthly mean of 24°C off Shark Bay to a winter monthly mean of 14°C near Albany (Royal Netherlands Meteorological Institute, 1949).

Extreme temperature readings, taken within a few yards of the source of specimens for present experiments, at Cottesloe Beach (near Perth) at various times from 1944 to 1954 are summarised in Table 1.

TABLE I

Locality temperatures at Cottesloe Beach

Location	Temp. ° C
rock surface in sun	up to 44·0
air shade	6·1 to 33·2
rock pools	7·6 to 34·6
sea at shoreward edge of reef flat	10·0 to 27·3
surf at outer reef edge	14·7 to 23·5

Methods and Results

Temperature observations on the chitons can be grouped under the main headings:

(i) Temperature variations within one chiton.
(ii) Field measurements in the normal habitat.
(iii) Field measurements in an extreme habitat.
(iv) Laboratory experiments on thermal death point in sea water.
(v) Laboratory experiments on thermal death point out of sea water.
(vi) Effects of desiccation.
(vii) Behaviour observations in relation to temperature.

† Data from the Perth Office of the Commonwealth Bureau of Meteorology.

Field measurements were carried out at Rottnest Island (32°S, 115°25' E) during November 1951 and at Cottesloe Beach in December 1954 and January 1955, and laboratory observations were made during the summer periods 1951-52 and 1954-55 on animals collected from Cottesloe Beach. Fresh specimens were brought in for each set of observations and were kept in laboratory conditions for some hours prior to commencing any heating experiments. In all laboratory experiments a set of control chitons were treated similarly to the experimental animals except that they were not heated.

All temperatures were recorded with a Cambridge skin temperature thermocouple, and sea water and air temperatures were checked with a mercury thermometer. Humidities were recorded using an Edney torsion hygrometer and checked where possible with a wet and dry bulb instrument.

(i) Temperature variation within one chiton

Animals were taken from sea water at 21.2°C and placed on a smooth glass surface in air at 24.9°C and relative humidity, 54% in the laboratory. After five minutes to allow the chiton to settle readings were taken inserting the thermocouple in different parts of the body. Handling the animals was avoided as far as possible and when it was necessary to shift the animal to insert the instrument (e.g. readings in the foot) the animal was replaced and held in contact with the glass plate by a plastic rod. Readings were taken with chitons on a wet surface and on a slightly warmed dry surface. The results are summarised in Table II, and show a variation within one animal of from 1.0°C to 2.6°C.

TABLE II

*Temperatures of various parts of individual chitons (measured in °C)**

Chiton	A	B	C	D	E
AIR	24·9	24·9	24·9	24·9	24·9
SURFACE	29·6	28·9	22·8	22·8	22·8
girdle	25·9	25·8	21·8	22·6	22·8
gills	25·4	27·4	23·0	23·5	22·4
foot	26·7	28·3	24·1	22·5	22·0
mouth	25·8	27·6	21·5	22·8	22·8
anus	25·3	...	22·9	22·9	23·5
visceral mass	26·1	27·7	23·3	22·8	23·3
between foot and glass		....	....	21·9	22·6

* Animals A and B on a dry plate, C, D and E on a wet plate.

(ii) Field measurements in the normal habitat

Observations were made on chitons (*in situ*) in the undercut at various points along approximately one half mile of shore line at Rottnest Island, reading in each case air, rock surface and animal temperature. The thermocouple needle was inserted through a small hole pierced in the girdle of the animal and was pushed in far enough to be in contact with the lateral wall of the visceral mass. The chitons showed no obvious ill effects from this treatment and the same animals could be used repeatedly without them detaching from the rock surface.

One hundred and twenty-four readings were taken over a range of rock temperatures from 16.2° to 34.0°C. Experimental animals were

selected at random except that for the higher temperature group it was necessary to choose animals continuously in the sun.

The results are expressed graphically in Fig. 2. In some cases the range of animal temperatures associated with a particular rock temperature is wide, and this can be explained in part by the field notes on recent shading or wetting of individuals although often it was not possible to record quantitatively these microclimate variations.

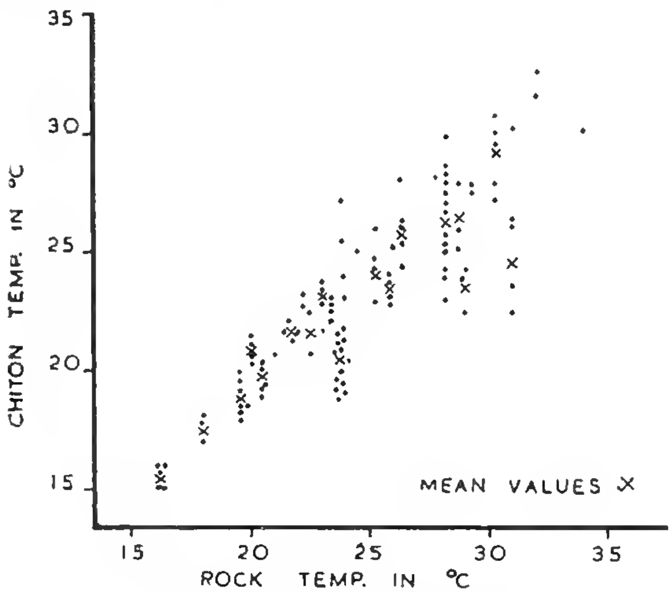

Fig. 2.—Temperatures of chitons (in the field) plotted against rock temperatures.

The geometric means plotted show a correlation between rock temperature and chiton temperature within the range of temperature variation of one animal, except in the groups of recently wet or shaded specimens where the mean animal temperature (24.5°C) was 6.5°C below the rock temperature.

(iii) Field measurements in an extreme habitat

Several readings were made during one day on small groups of animals in sunny and exposed conditions not typical of the usual situation in the undercut of *C. hirtosa*. The temperatures of individual animals followed the changes in rock temperature closely. Once covered by the incoming tide both the rock surface and the chitons returned to the water temperature. One set of these readings is shown in detail in Table III.

TABLE III

Variation of temperature of a group of chitons

Time	Air T. ° C	Rock T. ° C	Sea T. ° C	Chitons T. ° C				
				A	B	C	D	E
0645	18·3	18·0	....	17·7	17·8	17·3	17·5	17·6
0935	23·8	23·8	....	20·7	20·5	21·2	21·6	21·6
1240	26·8	25·2	....	24·2	23·0	26·0	24·7	24·2
1500	23·2	30·3	....	30·0	30·8	28·0	29·8	27·2
1725	23·3	21·6	21·6	21·5	21·7	21·4	21·7	21·7

The close correlation between chiton temperature and rock temperature, the rate of change of these two temperatures (Table III), also the temperature lowering shown by some animals (Fig. 2), suggested that there was some temperature control mechanism. The temperature changes of a group of chitons including living and dead animals and dead animals kept wet were measured. It was assumed that this would show whether or not living *Clavarizona* can control body temperature.

The chitons were taken from the undercut at Cottesloe Beach and reattached to the rock on the upper surface of the visor (about two feet vertically above their original position) in sunshine. The dead animals were killed by immersion in hot (70°C) sea water for ten minutes and were fixed to the rock surface with clear plastic adhesive tape. Readings were taken over a period of ninety minutes and the "dead-wet" chitons were damped after each reading with sea water at 23.3°C (the water and rock temperature from which all animals were originally taken). The wind velocity one foot above the rock surface where the chitons were attached varied during the experiment from 5 to 10 miles per hour. The results are shown graphically in Fig. 3.

The similarity of the readings from living and dead animals shows clearly the lack of any temperature regulating mechanism in *C. hirtosa*, while the lowered temperatures recorded from the dead-wet specimens show the physical effect of evaporation.

The living chitons responded normally when returned to sea water.

(iv) Laboratory experiments on thermal death point in sea water

Heilbrunn (1943) points out that the lack of details regarding rate of heating has marred otherwise useful records of heat death. In order to make these results comparable with other work (Gowanloch and Hayes (1926), Broekhuysen (1940) and R. G. Evans (1948)) a standard rate of 1°C per 5 minutes was adopted. R. G. Evans (1948) states that "this is sufficiently slow to make any lag between the body temperature and that of the surrounding water small enough to be neglected."

Additional experiments were carried out with the rate of heating slowed down to 1°C per 15 minutes which was considered to be more nearly the rate met with in nature and with the rate speeded up to 1°C per minute to note any variation in reaction to different rates of heating. In each case the chitons were kept at the final temperature for from three to five minutes.

Direct transfer from seawater at 26°C to seawater at various temperatures up to 45°C (as in the experiments of Arey and Crozier (1919)) was considered unsuitable.

The observations were made on animals heated in dishes approximately 15 cm in diameter and holding 500 ml of seawater. The number of animals per bowl was restricted to five as it was considered that this should provide a suitable amount of available oxygen and space for the chitons. These bowls were heated several at a

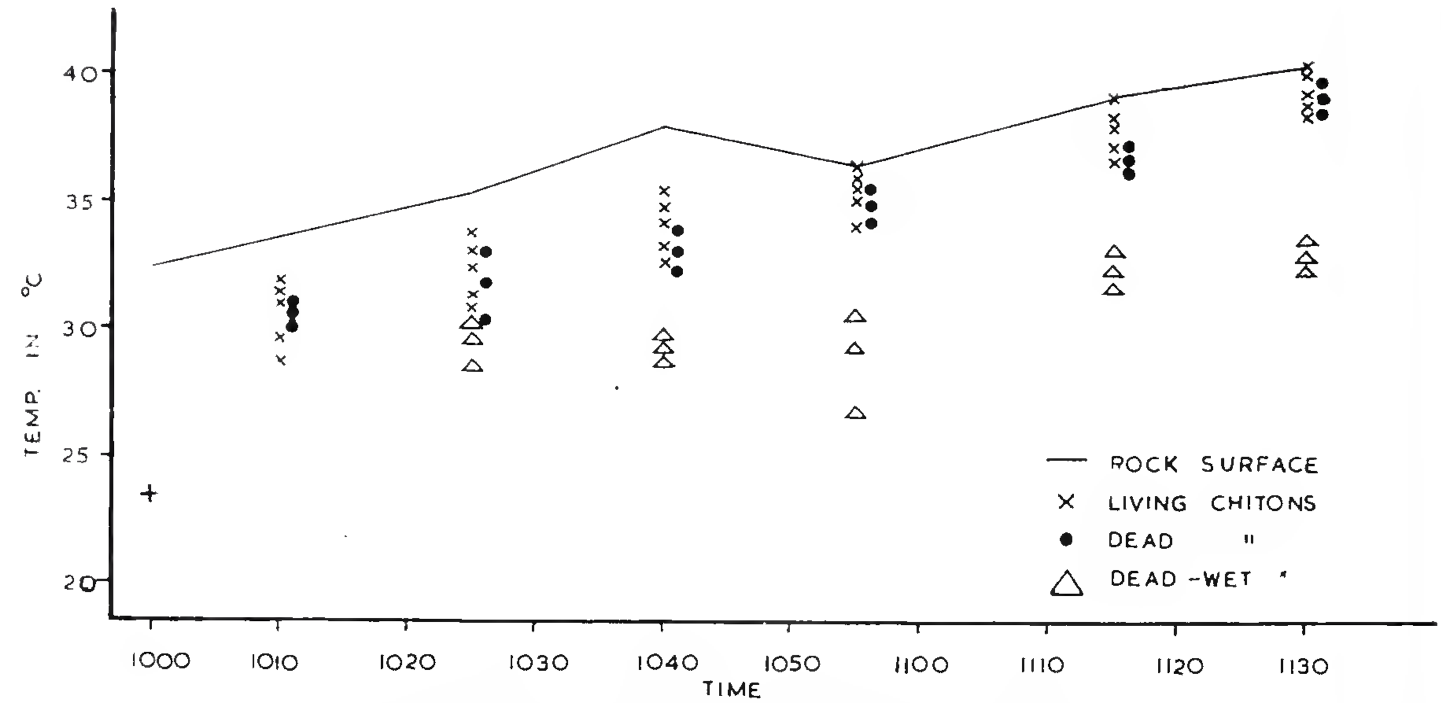

Fig. 3.—Temperatures of living and dead chitons (in the field).

time in a large water bath and temperatures were read in the bowls, not in the water bath. Aeration throughout the heating period and after was effected by vigorous stirring. No depletion of water volume was noted during any of the experiments.

After subjection to the particular temperature desired the animals were removed from the water bath (remaining in the warmed sea water) and allowed to cool to air temperature. When the heated water had returned to room temperature it was replaced by fresh sea water; this, depending on the rate of cooling, was done from three to six hours after the conclusion of the heating period. Twenty four hours were allowed for the chitons to revive and during that time the water was renewed several times.

The chitons were then tested for response to stimulation, the foot being pricked by a needle, and animals showing no response were considered dead. The lethal temperature was taken as that which killed fifty per cent of the animals tested.

TABLE IV

Lethal temperature of C. hirtosa in sea water

Final T. °C	Rate of Heating					
	1°C/5 min.		1°C 15 min.		1°C/1 min.	
	No. of animals heated	No. surviving	No. of animals heated	No. surviving	No. of animals heated	No. surviving
38	7	7	5	5	5	5
40	7	7	10	4	5	5
41	9	9	7	1	5	3
42	11	10	5	0	5	1
43	23	8	5	0	5	0
44	10	0				

The lethal temperature in seawater of *C. hirtosa* was determined as 43°C for a 1°C per 5 minutes rate of heating, 42°C for a 1°C per minute rate and 40°C when heated at 1°C per 15 minutes. Table IV summarises the details of these experiments.

A comparable set of heating experiments, at 1°C per 5 minutes, was carried out using animals taken from the reef rim and it was shown that the lethal temperature for this group of chitons was 41°C. (Table V).

TABLE V

Lethal temperature in sea water of C. hirtosa from the reef rim
Rate of heating 1° C per 5 min.

Final T °C	No. heated	No. surviving
38	5	5
39	5	5
40	10	6
41	10	4
42	5	0
43	5	0

In order to relate thermal death to length of exposure to particular temperatures, as suggested by Heilbrunn (1943) groups of chitons were heated (as described above) at a rate of 1°C per 5 minutes to final temperatures from 38° to 44°C and held at these temperatures for varying lengths of time. (Table VI). It will be seen from the table that although only a few animals survived exposure to 43°C for 5 minutes, at 41°C or less death was produced only by prolonged exposure.

The experiment at 38°C was discontinued after two and one half hours.

(v) Laboratory experiments on thermal death point out of sea water

Experiments on the effects of temperature on *Clavarizona* out of sea water were carried out with animals placed on a dried enamel surface in the laboratory. Both wet and dry bulb air temperature readings were taken and the humidity in the proximity of the testing plate was checked frequently with the Edney instrument. The test plate was heated over a water bath.

TABLE VI

Tolerance of C. hirtosa to prolonged heating in seawater

Temp. ° C	Time (in minutes after reaching T.)																							
	5		10		15		20		25		30		45		60		75		90		120		150	
44	10	0																						
43	23	8	5	0																				
42	11	10	10	2																				
41					12	9	12	7	12	6	12	5												
40							7	7			5	5	5	5	10	8	12	6	10	3				
38															10	10					10	8	10	9

In each column—the first figure = no. of chitons heated, the second figure = no. of chitons surviving.
Laboratory air temperature varied between 22·7° C and 29·4° C.

In order to check the time required for chitons to assume the temperature of the surface a group of five animals was taken from sea water at 23.1°C, placed on a dry surface at approximately 40°C, and kept there until the animal temperatures were stable over a period of ten minutes.

The frequent readings necessary made it impossible to check each animal as often as would be desirable but the graph of the results (Fig. 4) shows that the temperatures of different chitons at any one time were reasonably similar.

Within ten minutes the specimens had reached stable temperatures varying from 38.6° to 40.7°C and maintained these for a further ten minutes. The slight variations in the recorded surface temperatures were within the range of variation in a single chiton.

In order to compare the death point due to heat in air with that previously recorded in sea water groups of *C. hirtosa* were heated on a dry plate. The procedure used was the same as in the sea water experiments, the rate of heating being approximately 1°C per 5 minutes. As small variations in the temperature of the enamel surface were common and the lag between surface and animal temperatures was not constant, the final temperatures read were those of the chitons and not of the plate. The interval between final temperatures was limited to 2°C.

The thermal death point was 42 to 44°C. The detailed results are listed in Table VII.

TABLE VII

Lethal temperature of C. hirtosa out of sea water

Temp. ° C	No. of animals heated	No. of animals surviving
30	3	3
35	3	3
38	5	5
40	6	5
42	20	12
44	10	2

Other animals were tested while attached to damp and dry slabs of limestone, taken from Cottesloe Beach, both in-doors and in a sheltered but sunny situation. The varying rates of evaporation from the rock surface and of temperature increase and changes in relative humidity made the results difficult to analyse and they are not recorded here. However it is worthy of note that those animals removed at 42°C or less revived, while those (six in number) submitted to higher temperatures did not.

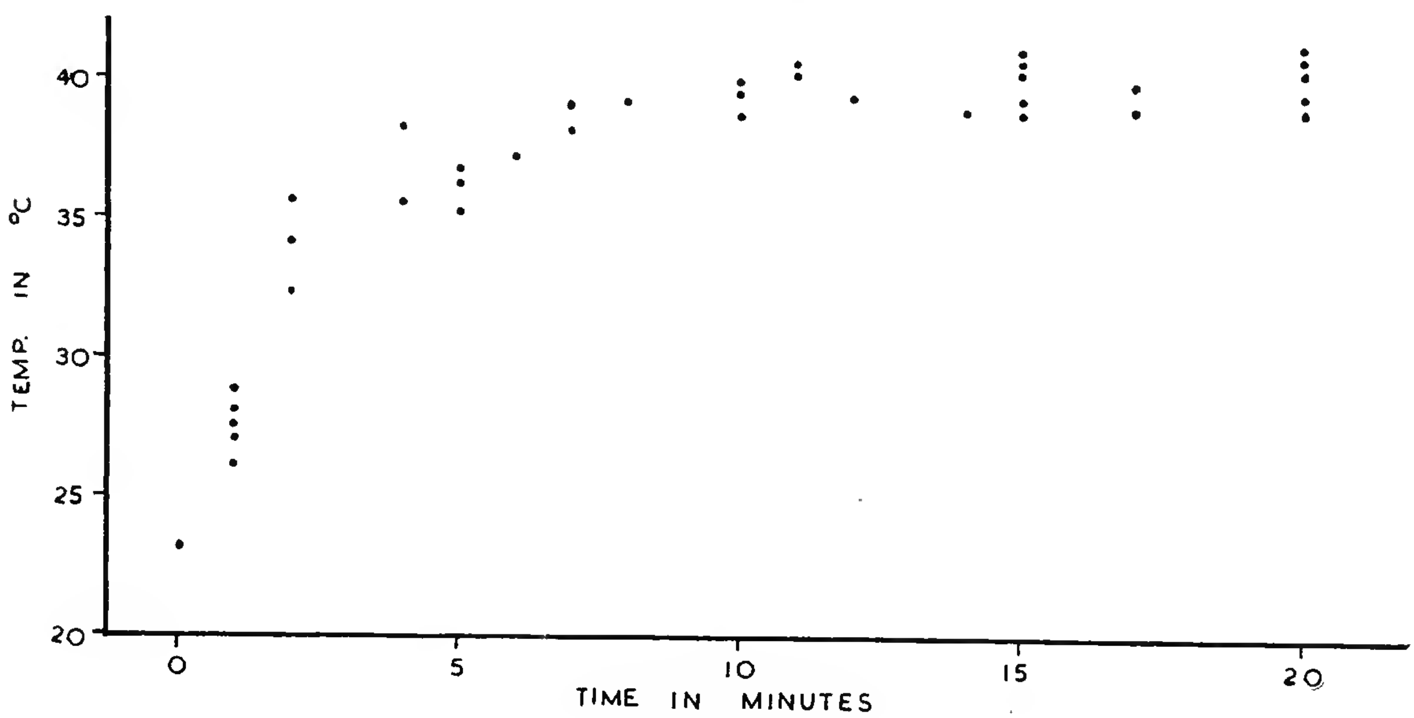

Fig. 4.—Time taken for chiton temperature to stabilise (in the laboratory).

A group of chitons from the reef edge was heated on the test plate in the laboratory. Four out of five animals survived exposure to 40°C for 5 minutes, but all chitons heated to 42°C died.

Groups of specimens were transferred from water to the test plate which had previously been warmed to 40°C, and were kept on the plate for varying periods. The length of time that the animals were kept at 40°C was noted from ten minutes after they were attached to the heating plate. In order to keep the chiton temperatures at 40°C (± 1.0°C) it was necessary to vary the plate temperature (up to 43.5°C at one period).

The water temperature, from which the chitons were taken and to which they were returned, was 21.8°C, air temperature 23.6°C and the relative humidity 62%.

The experiment was discontinued after ninety minutes (i.e. 80 minutes at 40°C) as it was considered that exposure for this period may cause death from desiccation (see section vi below). The results are inconclusive (Table VIII).

TABLE VIII

Chitons in air, kept at 40° C

Time (after stabilisation)	No. heated	No. recovered
20 mins	5	5
50 mins	10	7
80 mins	5	4

(vi) Effects of desiccation

In the above experiments on chitons out of seawater, the possibility of death being due to the combined effects of heat and desiccation was appreciated but not considered. The experiments were repeated to measure water loss.

Individual chitons were dried with filter paper and weighed (this weight being taken as the standard weight) before heating. At intervals animals were removed from the heating plate, reweighed and returned to seawater. The water loss was calculated as a percentage of the standard weight.

Figs. 5 and 6 show the details of these experiments graphically.

The range of the results makes any definite correlation between either rate of heating or final temperature and loss of weight difficult. The rate of dehydration is greater at higher temperatures initially, but the curve of dehydration rate tends to flatten off after approximately 60 minutes heating. The animals at 40°C for the total period of time lost a greater amount of water than those heated gradually (the mean values for 60 minutes being 16% and 10% respectively). Of animals showing a 15% or greater water loss, 7 out of 10 failed to recover. The lowest percentage water loss at which death occurred was 9%.

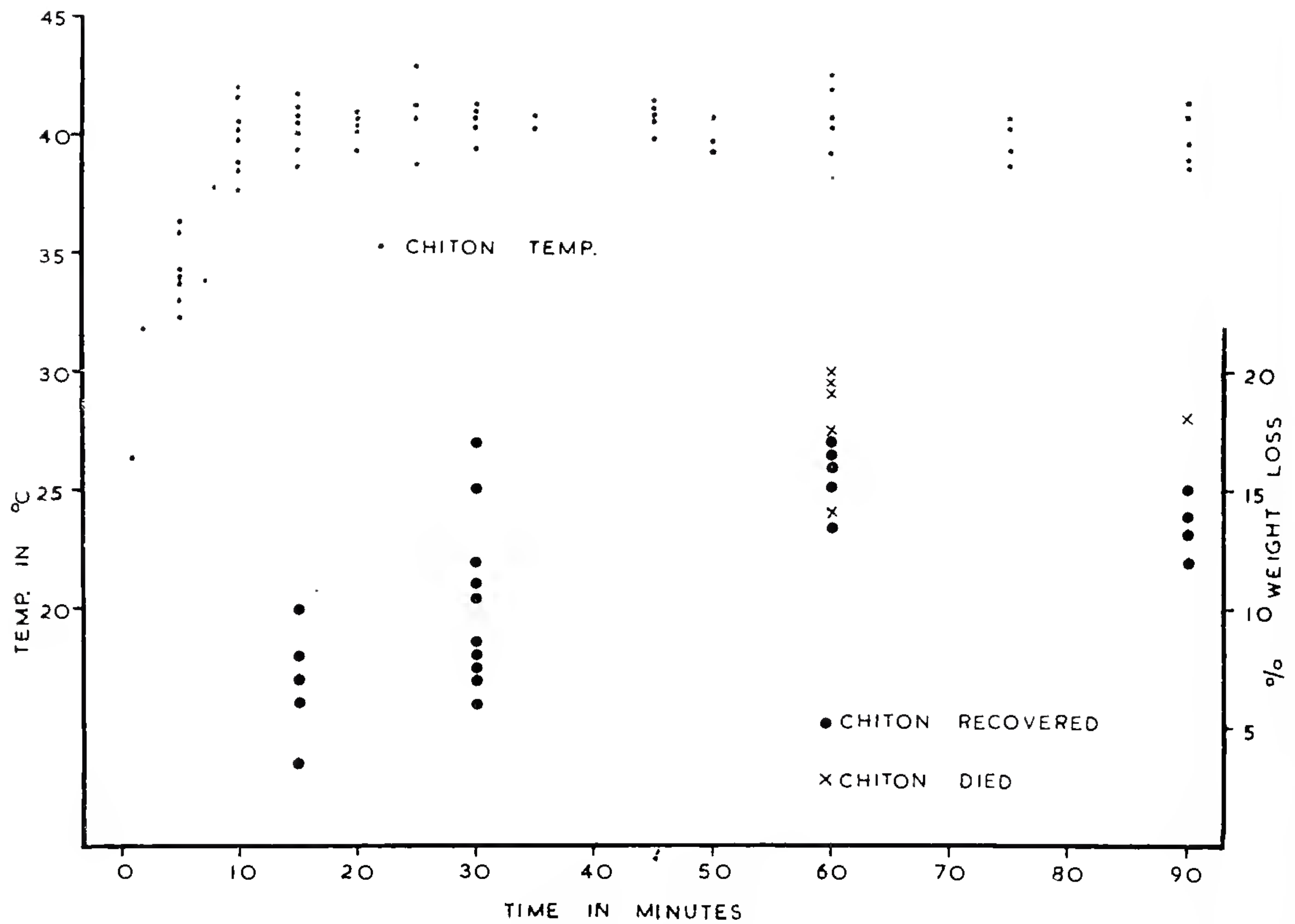

Fig. 5.—Percentage weight loss by chitons kept at 40°C.

(vii) Behaviour observations in relation to temperature

Throughout the experiments notes on the behaviour of the chitons were taken.

At temperatures near 30°C many of the animals being heated in sea water became more active and as well as moving quite rapidly up the sides of the bowls, tended to rear up in a "rampant position" remaining attached to the glass surface by only a small area of the foot. In the low thirties active crawling usually ceased and some animals raised the girdle. From 33°C upwards the ability to remain attached to the glass surface appeared to be lost, though in some cases the test animals remained fixed to the side of the bowl, by mucus, even after reaching the lethal temperature. At approximately 34°C all activity stopped and in general the chitons remained quiescent at higher temperatures.

No major difference in the reaction to particular rates of heating was noted though at the slower rate (1°C per 15 minutes) no chitons detached from the surface below 36°C.

Specimens heated in air on the test plates in the laboratory showed no special reactions. Chitons which were only partially in contact with the surface showed the same rate of temperature change as those that were firmly fixed.

Some animals heated on limestone detached at approximately 36°C, but detached animals revived as readily as those at the same temperature which had to be removed forcibly. In this experiment one chiton crawled to the shaded undersurface of the rock when the limestone temperature was 29.0°C and the animal's temperature 26.5°C.

No difference in behaviour was noted in chitons collected from the undercut and those taken from the reef rim.

Discussion

Writing on *Chiton tuberculatus*, from Bermuda (lat 32°N), Arey and Crozier (1919) state, "Temperatures of 44°C to 45°C are almost instantly fatal, although Chiton will survive for nearly two hours after sudden transference to a temperature of 40°C." These results are similar to those obtained with *Clavarizona hirtosa* i.e. 50% death at 43°C (5 minutes), no survivals at 44°C (5 minutes) and a 50% death after 75 minutes at 40°C. Thus similar heat death points have been recorded for two species of chitons from somewhat similar climatic regions.

It has been shown by Huntsman and Sparks (1924) that marine organisms have a degree of resistance to heat correlated with the temperature ranges the species experience in nature and Gowanloch and Hayes (1926) have demonstrated that animals of the same species from different tidal levels have different lethal temperatures (see also Broekhuysen (1940), in the Introduction). The results of these experiments with *C. hirtosa* conform to this pattern, individuals from the undercut having a higher lethal temperature (43°C in seawater) than those taken from the reef rim (41°C in seawater).

From the figures available (Table 1) and field observations, the difference between the maximum temperatures likely to be met by these two populations would be much greater than the difference between their thermal death points.

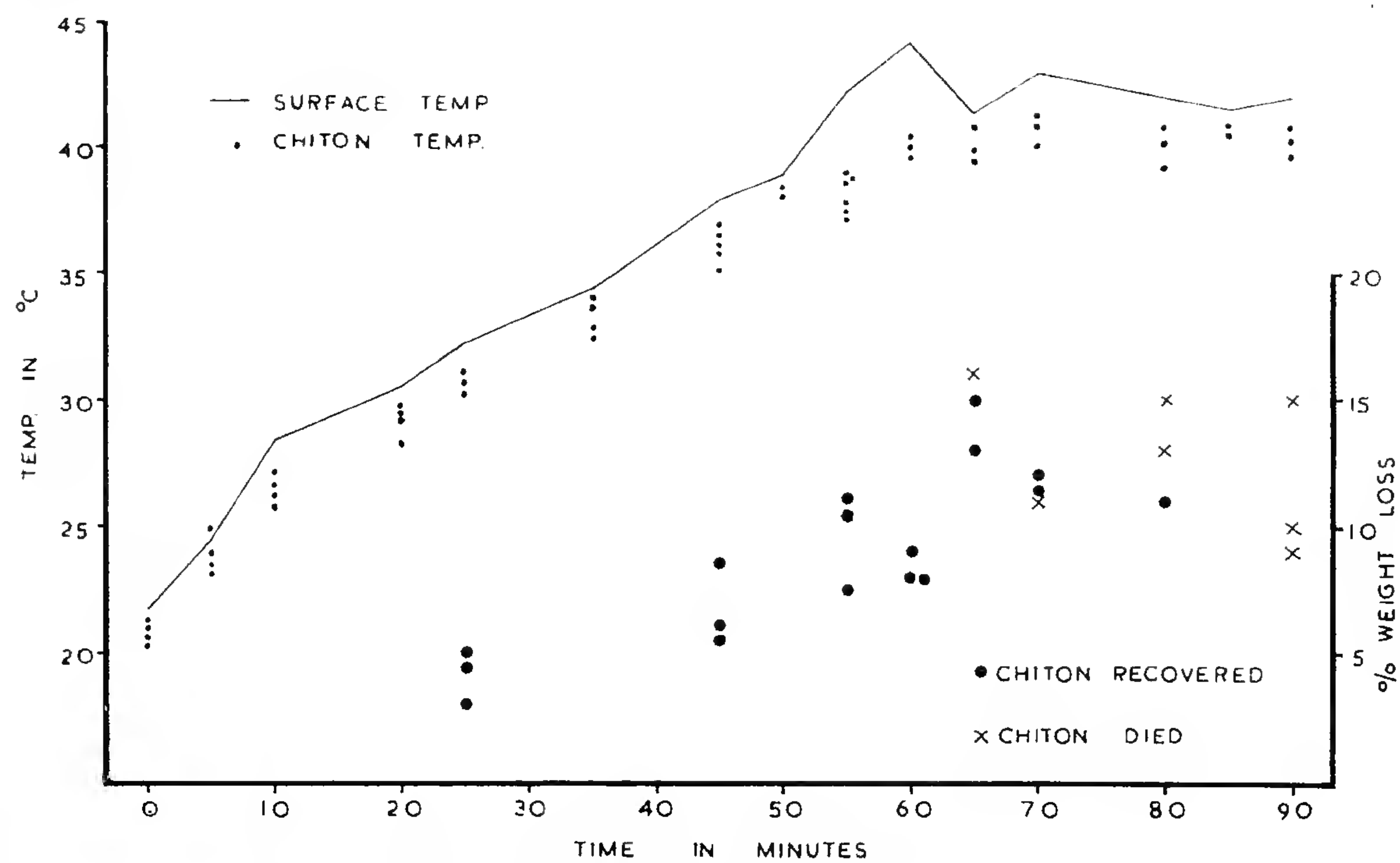

Fig. 6.—Percentage weight loss by chitons gradually heated to 40°C.

Heilbrunn (1943) states, "ordinarily dry heat does not kill as readily as wet heat." Although in the case of *C. Hirtosa* there is no difference between the temperature producing death in water and in air this species is more tolerant of sustained high temperatures in air. Specimens kept at 40°C in air for a period of ninety minutes were much less affected than those treated similarly in sea water (only 3 out of 10 animals surviving in the latter instance).

Hogben and Kirk (1945) found that the slug *Arion ater* and to a lesser extent *Helix pomatia* behaved as a wet bulb thermometer, with the cooling effect of evaporation preventing the body temperature from rising to that of the surrounding medium, unless the air was fully saturated. The snail when withdawn into the shell assumed a temperature considerably above that of the wet bulb and more nearly followed the dry bulb temperature. The slug, being shell-less was not able to control the loss of water by evaporation and remained at a lower body temperature even when the surrounding medium was at a temperature above the danger level for the animal.

C. hirtosa however is dependant on the temperature of the substrate and surrounding air temperature is only of importance in so far as it affects the rock (or other surface) temperature. The similarity of the reading obtained from living and dead chitons show clearly that there is no temperature reducing factor controlled by the animal, while the different temperatures recorded from the dead-wet specimens give some indication of the degree to which evaporation could lower body temperature if a mechanism for the control of temperature by evaporation did exist. However, it should be pointed out that in the experiment the whole dorsal surface including the shell was available for continued evaporation, whereas if evaporation was being used by the animal as a temperature control mechanism the surface would not be redamped periodically and that evaporation from the surface of soft tissues (e.g. mantle cavity and gills) would eventually result in complete desiccation.

Broekhuysen (1940) working with various intertidal molluscs in South Africa (where climatic conditions are similar to West Australia) found that "the minimum percentage of water loss at which death occurred" at 40°C was 10% for *Oxystele variegata* (Anton) and 13% for *Thais dubia* (Krauss). These two species have vertical ranges comparable with *C. hirtosa*. He further showed that they were slightly more tolerant of desiccation at room temperature.

Lepidochitona cinereus (L) specimens kept in still dry air (over calcium chloride) at room temperature for seven hours by F. G. C. Evans (1951) showed a mean loss of weight of 12% and, of 14 animals tested, 2 were dead. After 22½ hours all the chitons had died and the average weight loss was 52%.

Although F. G. C. Evans' experiments were carried out at room temperature and Broekhuysen does not state the duration of his experiment the figures for minimum water loss causing death are similar to that obtained for the West Australion chiton (9% loss of weight after 90 minutes).

Direct comparison between the rate of dessiccation of *Clavarizona* and Broekhuysen's molluses is unreasonable as the South African species used were gastropods, presumably capable of controlling desiccation to some degree by closing the operculum. However the flattening of the rate of desiccation curve mentioned by Broekhuysen is paralleled in the case of the chiton although the rate is much more rapid, *C. hirtosa* specimens kept at 40°C for 90 minutes having lost 15% of body weight while an equivalent water loss from *Thais dubia* at room temperature took 20 hours.

The figures (for species with similar vertical distribution to *C. hirtosa*) listed by Broekhuysen (1940) as "temperature at which activity stopped" and by R. G. Evans for "inactive but responding to stimulation", vary from 32°C for *Littorina littorea* (L) to 37.2°C for *Oxystele variegata* (Anton). These are similar to the 34°C cessation of activity of *Clavarizona*.

Clavarizona situated, as it is typically, in the undercut and at the reef edge would not normally be faced with temperatures approaching the lethal point, but extreme conditions of low tides in the hottest part of the day during the summer period certainly do produce rock temperature up to 44°C on the visor (see Fig. 1). The few chitons observed occurring naturally at this level tend to be situated in small crevices apparently making use of the meagre shade available, or in rock pools. Fig. 2 shows clearly the body temperature variation produced by factors of the microclimate.

The damp shaded conditions of the undercut would rarely produce extreme desiccation conditions but raising the chitons two feet vertically would in many cases place them in a position where low humidities occur frequently during the summer months and since they would remain exposed to the air for prolonged periods a water loss of 15% would be probable.

R. G. Evans (1948) comments, "From what is already known it appears probable that the effects of temperature acting as an isolated factor (i.e. pure temperature effects) are of subsidiary importance to the drying action of supernormal temperatures in controlling the upper limits of distribution of littoral plants and animals." Presumably this would only apply to chitons if they were detached from the rock surface.

The pure temperature effect necessary to kill *Clavarizona* is approximately 10°C above the temperatures recorded in the undercut in the field although higher temperatures may occur. It is in the undercut that the majority of the population occurs and this suggests that extremes of heat and desiccation that will kill *Clavarizona* are rarely experienced in this niche.

These experiments were done on animals from the middle of the geographic range of *Clavarizona* and it is probable that specimens from the northern extreme of the range may show effects of acclimatisation to the overall warmer conditions, although the extreme air temperatures recorded from Perth are similar to those recorded at Carnarvon (six degrees of latitude further north).

Acknowledgments

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14.—Notes on the Regeneration of Vegetation of Garden Island after the 1956 Fire

By Alison M. Baird*

Manuscript accepted—27th June, 1958

Garden Island has been visited at intervals over two years since the fire at the end of January, 1956, and photographs taken and specimens collected of the regenerating vegetation. The *Acacia rostellifera* scrub, the major community of the island, is regenerating well from root suckers. The tree species, *Callitris robusta* and *Melaleuca pubescens*, are both killed by fire but are regenerating from seed. *Melaleuca* after two years' growth is both taller and in denser stands than the *Callitris*. Seedlings of the subordinate shrub species such as *Spyridium globulosum* are still less than one foot high. In the second year after the fire the most conspicuous plant in the burnt areas was the semi-herbaceous, quick growing, relatively short lived plant, *Solanum simile*, but by the end of the second summer this was waning and being overtopped by the regenerating *Acacia*. Since the fire the ground has been exposed to leaching by the heavy battering winter rains, and to sun and wind: conditions very different from those of the unburnt scrub where the soil is in heavy shade and doubly protected by the dense canopy of the shrubs and the deep litter on the surface. It will be many years before the vegetation regains its former height and density and the organic matter of the soil is restored. Observations on the regeneration will be continued.

Introduction

The vegetation and soils of Garden Island, lying off the coast of Western Australia, near Fremantle, Western Australia, were observed by McArthur in 1952 (McArthur 1957).

At the end of January, 1956, a devastating fire swept through the island destroying the vegetation of practically the whole central region—probably of the order of two-thirds of the total area. The region south of the settlement escaped, part of the northern end and small patches along both eastern and western shores. This destruction of such an area of virgin scrub represents a botanical disaster as there is little such vegetation remaining in its more or less natural state. Coastal areas on the opposite mainland which once had similar vegetation have been drastically changed and depauperised by clearing, grazing, frequent fires and the invasion of weeds; and the neighbouring island, Rottnest, has only fragments remaining of its original vegetation cover.

The records on which this paper is based were made on a few trips with only three to four hours on the island; hence there is no claim to a thorough study of the regeneration but failing more detailed work there is justification for publishing this incomplete survey. Many photographs in both kodachrome and black and white were taken and specimens collected of the regenerating plants. These are housed in the Botany Department, University of Western Australia.

The areas visited were along the path cutting across the island from the settlement on the east to the west coast, and between the settlement and a point half a mile north of Colpoys Point (see Fig. 1). Although this represents only a small part of the area the main vegetation types are covered. From east to west the track passes through mixed scrub—*Acacia rostellifera*, *Melaleuca huegelii* and *M. pubescens* with *Spyridium globulosum* merging into a broad zone of tall dense *Acacia rostellifera* scrub which, as the dune areas of the west coast are approached, becomes much lower (Plate I, 2) and contains an admixture of dune species. The dense canopy of this scrub before the fire is shown in Plate I, 1, and a fragment in profile in Plate I, 4.

Along Careening Bay there is again *Acacia* and mixed scrub. At the Point, and scattered through the mixed *M. huegelii* and *Acacia* scrubs of the Colpoys Peninsular there are tall stands of *Melaleuca pubescens* - *Callitris robusta* (Plate II, 3). Some small patches near the shore escaped destruction in the fire, and others were killed without the tops being actually consumed by

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PLATE I.

No. 1.—Photograph taken before the fire looking north to dense *Acacia* scrub on the far side of the east-west path which is indicated by the diagonal line across the picture. May, 1955.

No. 2.—The low western edge of the *Acacia* scrub where it merges into the dunes. *Senecio lautus* in flower on both burnt and unburnt sides of the path. November, 1956.

No. 3.—A stand of tall *Acacia* where regeneration was practically non-existent. November, 1956.

No. 4.—Looking from a burnt into an unburnt part of *Acacia* scrub showing the dense tangle of stems—some regrowth in foreground. April, 1958.

No. 5.—Regrowth from the base of an old *Leucopogon richii* plant, regeneration otherwise very poor. November, 1956.

No. 6.—An area of very good *Acacia* regrowth.

No. 7.—An eroded slope with horizontal roots of *Acacia* exposed. A few *Acacia* shoots and small seedlings of *Melaleuca*. November, 1956.

No. 8.—A vigorous clump of *Acacia* suckers (upper left), *Thomasia* and *Stipa*. November, 1956.

No. 9.—An area of good *Acacia* regrowth more than two years after the fire. April, 1958.

PLATE I.

PLATE II.

fire; but the stands further inland were drastically burnt, the whole of the upper canopy being burnt off leaving a forest of bare sticks (Plate II, 5).

Regeneration

November-December, 1956.—The island was first visited in mid November, 1956, ten months after the fire, and then again early in December, i.e., after a complete winter and spring following the fire. The scene was still one of devastation with blackened dead stems and extensive areas of bare white or grey sand. Regeneration was, however, well started. In the *Acacia* scrub there was some very good regrowth particularly on the fringes of the dense thickets and in the more open areas, with clumps of suckers up to a foot long, from roots either close to the parent plant or several feet away. Plate I, 6 shows an area of good regrowth and Plate I, 3 a poor one. No *Acacia* seedlings were seen in the heavy *Acacia* scrub but they were common in the more open areas of mixed scrub near the settlement and along the edge of Careening Bay. The heat must have been so intense in the dense scrub that any seed present had been destroyed. Seedlings of shrub species which normally occur scattered through the *Acacia* scrub, e.g. *Spyridium globulosum, Eremophila glabra,* were present in small numbers, being mostly about 1-3 inches high. The roots of all the seedlings were very much longer than the tops—usually exceeding 1 foot on seedlings only 2-3 inches high.

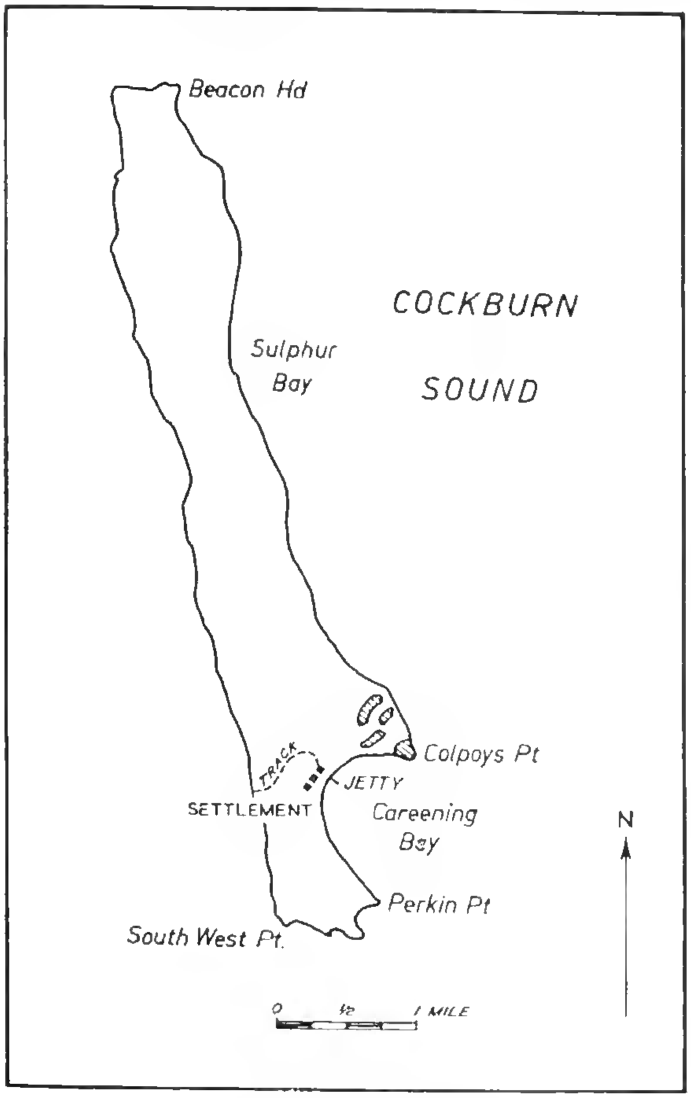

Fig. 1.—Map of Garden Island.

In the mixed scrub, small seedlings of the associated tree species, *Melaleuca huegelii* and *M. pubescens* were numerous in the immediate localities of parent trees (some are visible but not easily identifiable in Plate 1, 7). Of the smaller shrubs *Phyllanthus* was regenerating from seed, but no regrowth was seen. *Thomasia* seedlings were very abundant in places with a few *Guichenotia* seedlings. The quick growing semi-herbaceous plant, *Solanum simile* was flourishing particularly in sheltered hollows but was widely distributed through all the burnt areas.

Herbaceous plants were unevenly distributed. *Senecio lautus*, in flower, covered the ground in places, being more abundant towards the sand dunes on the west side, and flowering equally well on burnt and unburnt sides of the track (Plate I, 2). *Didiscus cyanopetalus* a small herb, was abundant and widespread—in flower in November and in fruit in December, and also—but in smaller numbers — *Poranthera microphylla. Didiscus coeruleus* the "Rottnest Daisy" was seen in local patches only, (Plate II, 2). A small species of *Crassula* was concentrated in shallow depressions and around dead bushes. The dark patch between the *Solanum* plants in Plate II, 1 consists of closely packed *Crassula* plants. It appeared that seed had been washed into the hollows or against obstructions. This applied

PLATE II.

No. 1.—A depression in mixed scrub showing accumulation of ash washed into the hollow; *Solanum* plants with a dark mass of *Crassula* between them, scattered *Didiscus, Stipa* and *Melaleuca* seedlings. December 2nd, 1956.

No. 2.—An adjacent elevation, burnt *Melaleuca huegelii*, (overhanging branch to left) burnt *Callitris* tree (right), *Didiscus coeruleus* in flower (left), also other small annuals and seedlings of various species. December 2nd, 1956.

No. 3.—A stand of *Melaleuca-Callitris* which escaped the fire, showing the closed canopy and close spacing of tree trunks.

No. 4.—Interior of another small stand showing the thick carpet of litter.

No. 5.—A burnt stand of *Callitris-Melaleuca*, 10 months after the fire. Small seedlings of both species distributed sparsely over the bare stand. December, 1956.

No. 6.—Part of the same stand 16 months later. Young plants of *Callitris* (left) and *Melaleuca* (right of white trunk). April, 1958.

No. 7.—Another part of the stand with young plants of *Callitris* (back left), *M. huegelii* (in front of white stem), *M. pubescens* (extreme right) and *Didiscus cyanopetalus* the small annual on the shadow in the left foreground, *Solanum* through trees in the background. November 1st, 1957.

No. 8.—An area near the Beach. A dead *Callitris* tree, *Acacia* regrowth in centre foreground and a large plant of *Solanum simile* on the extreme right. November 1st, 1957.

No. 9.—A dense clump of young *Melaleuca pubescens*. The tallest plant in the background is *Solanum*. April, 1958.

also to other species—slopes where there had been obvious erosion were noticeably bare of annual plants and seedlings.

In the mixed *Acacia-Melaleuca* scrub along Careening Bay and beyond Colpoys Point similar regeneration was occurring. Acacia suckers were growing but also many seedlings, showing the compound leaves characteristic of the seedling stage. *Acanthocarpus* and *Stipa* were regenerating from old plants. *Leucopogon richii*, a woody shrub scattered sparsely through the area, showed vigorous regrowth from the base of the plant (Plate I, 5).

Erosion was evident where the ground sloped. Plate I, 8 shows horizontal roots of *Acacia rostellifera* exposed where sand had been washed away. There were some very bare slopes down into the hollows behind the dune fringe and evidence of accumulation of ash and charcoal in some of the hollows (Plate II, 1). The hills in the centre were not visited, but from the sea these appeared to be much barer of vegetation than the flats below. It is not unreasonable to suppose that these higher slopes suffered erosion of both soil and seed.

The mobile dune vegetation is no different from that along the mainland beaches and little time was devoted to the examination of it. The principal cover plants, *Olearia axillaris* and *Scaevola crassifolia* had been killed by fire. Seedlings were present but were still very small in December, 1956. The sedges, *Lepidosperma gladiatum* and *Scirpus nodosus* were regenerating from the underground rhizomes.

In the *Callitris-Melaleuca* forests the regeneration was from seed and the seedlings were still, after a full winter and spring growth, only from 1-4 inches tall. The dense stand of *Callitris* (Plate II, 5) is one of several on Colpoys Peninsular: it lies in a slight depression behind the beach sandhills. There had evidently been considerable wash of sand down the gentle slopes—the sand was bare except for the small sparsely scattered seedlings of *Melaleuca* and *Callitris*. They are difficult to see in the photograph and were not conspicuous in the field. Herbaceous plants were absent except for a small patch at the bottom of a depression. On the surrounding higher ground where the bush had been much more open, seedlings of *Solanum*, *Thomasia* and *Phyllanthus* and flowering plants of *Didiscus*, gave some conspicuous cover between the suckers of *Acacia* and the seedlings of *Melaleuca* and *Callitris*.

May, 1957.—At the beginning of the next winter, fifteen months after the fire, a very brief visit to the Colpoys Peninsular area showed that there had been considerable growth of the *Melaleuca* seedlings. There was less increase in the *Callitris* while the seedlings of the shrub, *Spyridium*, were still very small. Young plants of *Phyllanthus* which had survived were beginning to grow new shoots from stems which had been defoliated over the summer.

November 1st, 1957.—After another season's growth the general impression was of *Solanum simile* dominating the area. The more pronounced hollows and sheltered areas were occupied by big spreading leafy bushes up to five feet tall. Less massive plants occurred among the *Acacia* suckers. *Solanum* was present through all the communities seen, except on exposed rises and the western sand dunes. The rapid growth from the seedling of this herbaceous plant was in striking contrast to the slow progress of the seedlings of the long lived, woody shrub species such as *Spyridium* and *Beyeria* which were still only a few inches high. *Acacia* suckers had made good progress up to about three feet and were still growing vigorously though obscured in places by the *Solanum*. There were bare areas as noticed the previous year where the fire had been particularly intense.

Herbaceous plants, *Senecio lautus* and *Didiscus cyanopetalus* had flowered earlier than the previous year and were in fruit. Both were abundant as in the first year after the fire. *Crassula* was still present in large numbers, also *Poranthera microphylla*. At this time these annuals were dying off.

In the mixed scrub, both along the path to the west and along Careening Bay, *Melaleuca* seedlings of both species were now plants from 1-4 feet high. *M. pubescens* was taller on the average, while *M. huegelii* was more compact and bushy (Plate II, 7). *Phyllanthus* plants about one foot tall had flowered but were now very yellow and dry. *Thomasia*, spreading plants a foot or more in diameter and about the same height, were fairly widespread. *Pelargonium* and *Carpobrotus*, seen as small seedlings the previous year, were now spreading plants. *Guichenotia* was rare, except beyond Colpoy's Point where it was fairly common.

April, 1958.—Towards the end of a particularly long dry summer, the picture had changed. Whereas in October, *Solanum* had dominated the scene, in April the bushes though still alive, were yellowed and partly defoliated, while the *Acacia* regrowth from old established root systems had made considerably more growth. Though at that time growth had ceased, the leaves were still bright green, and the stems had thickened considerably since October. The *Melaleuca* seedlings had probably made some further growth and on the whole were in good condition but some had died, particularly where crowded. *Callitris* seedlings were not much bigger than when last seen, were very yellow and dry and obviously suffering water stress. Seedlings of *Spyridium* were still small. *Thomasia* plants although brown, did not appear to be dead. *Phyllanthus* which had made luxuriant growth in the first winter, and had flowered in the second, had suffered in the severe summer of 1957-8 and most of the plants seen were dead.

Discussion

The soil has not been studied. In view of the drastic change which has taken place, a study of the nutrient status of the soils on the burnt areas for comparison with McArthur's finding before the fire and a continued study of the regeneration or deterioration of the soil over the next few years seems to be highly desirable. It is unfortunate that such a study was not started immediately after the fire. The writer did not see the island until after a whole rainy season,

by which time the ash from the burnt region had been washed in. From reports of eyewitnesses, and from consideration of the amount of plant material consumed, this must have been in very much greater quantity than is usual after the more frequent fires on the mainland, and must have temporarily increased the soil mineral content greatly. McArthur found a very high nitrogen level, (for West Australian soils) under the long unburnt scrub. Evidence that the nitrogen level was high after the fire was the remarkable growth of the *Phyllanthus* seedlings. This species is known to react well to nitrogen manuring. It is widespread on the mainland and seedlings are common after bush fires. In the neighbourhood of Perth where it grows in Jarrah-Banksia woodland on sandy soils seedlings usually reach a height of only 2 or 3 inches in the first year and about 6-10 inches in the second year. On Garden Island they ranged in size from a few inches to a foot high in the first year, and the leaves were at least twice the normal size. Some seedlings brought from the island and planted beside local young plants near the University have after more than a year in the poorer sand approached much more closely to the usual condition—the leaves formed recently are only about half the size of those present when the seedlings were transplanted.

Notable in the unburnt bush on Garden Island was the deep plant litter and high organic content of the surface layers of soil. A year after the fire the soil was still bare and white, with only a small proportion of the surface covered by vegetation. After two years, although there has been regeneration as described, much of the soil surface is still exposed to sun and rain, and the amount of plant debris which has accumulated is extremely small. It seems that it will be many years—even assuming there are no further fires—before either the vegetation or the soil regains its former condition. The *Acacia* scrub suckering from the old plants will build up more quickly than the *Melaleuca* and *Callitris*. The *Acacia* is at present moving into the margins of the stands of *Callitris* and *Melaleuca*. No doubt the position could be reversed in time if the *Melaleuca* reaches tree size and overshadows the *Acacia*. McArthur (1957, p. 52) found evidence that the *Callitris* stands had been extending their range before the fire. At present the 2-year old *Melaleuca* plants are both taller and broader and more closely spaced than the *Callitris* ones, but in the stands seen there is so far little competition between them. Evidence from the former communities is that the two species grow happily together in dense stands both forming slender trunks and with similar canopies at the same level; this despite the very different shapes of isolated trees.

The regeneration of vegetation on Garden Island forms a striking contrast to that on Rottnest which was also devastated by fire a year earlier. Here regeneration of both *Acacia* and *Melaleuca* was effectively prevented by grazing by the quokka *(Setonix brachyurus)*. As *Solanum* is not eaten it was abundant on Rottnest as on Garden Island. Any effect of grazing of the regrowth by the Garden Island Wallaby *(Protemnodon eugenii)* was too slight to be noticed by the author in the brief visits. The small population of animals puts no pressure on the large areas of *Acacia* scrub. The only plants noted as having been cropped to ground level were one or two tufts of *Carex*, but very little of this plant was seen.

A feature of the reaction to fire of the coastal vegetation of the type found on Garden Island, but not peculiar to the islands, is the relatively small number of species capable of regenerating from underground parts, whereas in the typical mainland communities only a small percentage of the total species are killed by fire, and recovery of the bush is in consequence much more rapid. The list below shows behaviour of the commoner shrub species in this respect.

Species which sprouted from underground parts

Acacia rostellifera Benth.
Leucopogon richii (Labill.) R.Br.
Clematis microphylla D.C.
Lepidosperma gladiatum Labill.
Scirpus nodosus Rottb.
Stipa variabilis Hughes.
Acanthocarpus preissii Lehm.

Species which regenerated from seed only

Melaleuca pubescens Schau.
M. huegelii Endl.
Phyllanthus calycinus Labill.
Thomasia cognata Steud.
Guichenotia ledifolia J. Gray.
Beyeria viscosa (Labill.) Miq.
Spyridium globulosum (Labill.) Benth.
Boronia alata Smith.
Scaevola crassifolia Labill.
Olearia axillaris (D.C.) F.v.M.
Carpobrotus aequilaterus N.E. Br.

Reference

McArthur, W. M. (1957).—Plant Ecology of the coastal islands near Fremantle, W.A. *J. Roy. Soc. W. Aust.* 40: 46-64.

15.—The Stratigraphic Sequence in the Western Portion of the Eucla Basin*

By N. H. Ludbrook†

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Drill cores from four bores in the Western Australian portion of the Eucla Basin and two bores in the South Australian portion reveal a sequence of over 1,200 feet of Cretaceous mudstones, sandstones, and greensands overlain by a maximum of 900 feet of Upper Eocene and Lower Miocene limestones. An unexpected thickness of 900 feet of post-Albian greensands and mudstones is present in Madura No. 1 Bore. These are believed to be equivalent in part at least to the greensands of the Gingin District.

Introduction

Through the courtesy of the Government Geologist, Western Australia, cores from Madura No. 1, Madura No. 2, Exploratory Bore No. 3 337-mile peg Transcontinental Railway 28 miles west of Loongana, 245-mile bore Trans-continental Railway, and specimens from Murrawijinnie Cave, Murrawijinnie Bore and Delisser's Bore were made available for palaeontological study. The assistance of the Geological Survey of Western Australia in this matter is gratefully acknowledged.

Stratigraphic Sequence

Basement.—Highly metamorphosed Archaean basement rocks were entered at 1370 feet in 337-mile bore.

Mesozoic shales and sandstones.—The oldest sediments of the Eucla Basin so far determined were entered at the bottom of Madura No. 1 Bore where fossiliferous carbonaceous sandstones of Aptian age occur below 1979 feet, resting on laminated shales, the thickness of which is not proved.

Overlying the Aptian are 1050 feet of paralic sandstones and glauconitic sandstones grading to greensands of possible Albian to Santonian age. The greensands are poorly fossiliferous with fish remains and, rarely, tests of arenaceous foraminifera. In the upper portion of the interval the glauconite is characteristically bright green. These greensands apparently thin out to the north as they are not present in the 337-mile bore.

Correlation with the Molecap Greensand is suggested for part at least of this interval. From the Molecap Greensand plesiosaur bones, fish bones, a belemnite and pelecypoda have been reported (Fairbridge, 1953, p. X/2). In addition, the writer has recovered microscopic fish teeth and a small microfauna of arenaceous foraminifera including *Trochammina* spp., and radiolaria.

Many of the spherical glauconite grains are internal casts or dissolved and redeposited tests of radiolaria whose lattice shell pattern is microscopically discernible on the surface of the glauconite grains.

The Cretaceous glauconitic sands are overlain by Tertiary sands and limestones.

Fig. 1.—Cliffs of Great Australian Bight, south of Koonalda, view east, showing Nullarbor Limestone (dark) over Wilson Bluff Limestone (white).

Tertiary sands and limestones.—The base of the Tertiary is marked by 22 feet of limonitic quartz sand and gravel with polished limonite grains. Above this the Wilson Bluff Limestone of Upper Eocene age attains its maximum thickness of 873 feet in Madura No. 1 Bore. The limestone is a chalky bryozoal calcarenite with flint bands. It is to be correlated with the Torta-

*The present paper was submitted before the paper by M. J. Frost ("Jointing associated with the Hampton Fault near Madura, W.A." *J. Roy. Soc. W. Aust.* 41: 23-26.) came to hand.

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chilla Limestone of the Adelaide Basin and the limestone of Buccleuch "A" in the Murray Basin. On the Nullarbor Plain it is overlain by the dense crystalline Nullarbor Limestone (Lower Miocene) which appears to have been removed from the Eyre Plain by marine erosion. The microfauna of the Nullarbor Limestone is the same as that of limestone remnants near Kulpara on Yorke Peninsula. These are regarded as of "Batesfordian" age.

Outcropping Limestones of the Hampton Scarp

The writer has not personally visited the area west of Eucla, and knowledge of the outcropping limestones is limited to laboratory examination of rock specimens collected by geologists of Frome-Broken Hill Company Pty. Ltd. in 1954.

Fig. 2.—Cliffs of Great Australian Bight, south of Koonalda, view west. The cliffs are about 300 feet high at this point.

The Hampton Scarp, like the cliffs of the Great Australian Bight (see Figs. 1, 2), is composed of Nullarbor Limestone upon Wilson Bluff Limestone. Two and a half miles north of Eucla the Eyre Highway runs down the scarp to the Eyre Plain (see Fig. 3) over about 30-40 feet of dense, hard Nullarbor Limestone with the chalky bryozoal Wilson Bluff Limestone at the foot. Both are well exposed in a gorge to the west of the Highway.

The Nullarbor Limestone outcrops at the top of Kuthala Pass, 40 miles west of Eucla and forms the cliffs at Madura. Samples taken in the cliffs immediately behind the Madura Motel are of pink-coloured, hard, dense crystalline algal limestone composed largely of the remains of calcareous algae—*Lithothamnium*. The limestone has an attractive appearance when polished (see Fig. 4). In addition to *Lithothamnium*, the Nullarbor Limestone in this area carries a poorly preserved but characteristic microfauna with *Austrotrillina howchini* (Schlumberger) and small miliolidae and rotaliidae. Elsewhere in the Eucla Basin *Marginopora vertebralis* Blainville is generally present in association with abundant miliolidae, and commonly with *Austrotrillina howchini*.

Fig. 3.—Eyre (also Roe) Plain, from Hampton Scarp, 2½ miles north of Eucla.

Specimens collected at the base of the section west of Madura are of partially recrystallized and somewhat friable bryozoal calcarenite differing both lithologically and faunally from the Nullarbor Limestone. The megafauna includes the echinoids *Fibularia gregata* Tate, "*Lovenia forbesi* T. Woods", *Pseudechinus woodsi* (Laube), the mollusca *Chlamys eyrei* (Tate), *Chlamys gambierensis* (T. Woods), and *Eotrigonia semiundulata* (McCoy). Both the megafauna and microfauna are comparable with that of the Mannum Formation of the Murray Basin. It is not certain whether this limestone is a lower member of the Nullarbor Limestone, or, as described by Tate from Wilson Bluff (1879, p. 107), a unit distinct from both the Wilson Bluff and Nullarbor Limestones.

Fig. 4.—Algal limestone (Nullarbor Limestone) Madura.

The Hampton Scarp probably represents the Pleistocene shoreline rather than, as claimed by some writers, a fault scarp. The sedimentary cover of the Eyre Plain (also known as Roe Plain) is of Pleistocene age. Sandy limestones accessible in Madura Cave and penetrated in Madura No. 1 Bore have an abundant molluscan fauna of mostly living species together with several survivors from the South Australian Pliocene. The Nullarbor Limestone has been partially or wholly removed by marine erosion and the Pleistocene appears to rest directly on the Wilson Bluff Limestone.

Examination of the Bores

W.A. Government Survey Exploratory Bore No. 1, Madura

Location: Madura, about 30 chains south from face of Hampton Range escarpment.
110 feet above sea level
Reference 4880. Drilled P.W.D. 1902

0 -8′—Light loam.

8′-30′—Cream shelly limestone, with chalky molluscan shells in a recrystallized matrix, of Pleistocene age.

30′-508′—White bryozoal limestone. Only one sample available over the whole interval the exact depth of which is not stated. The limestone is composed almost entirely of remains of bryozoa. Diagenesis has proceeded too far for ready identification of the foraminifera which include *Textularia* sp. cf. *Stomatorbina torrei* (Cushman & Bermudez), *Gyroidina* sp. The boring entered the Wilson Bluff Limestone (Upper Eocene) in this interval.

508′-766′ 9″—Dense chalky limestone with chalcedonic bands, characteristic of the Wilson Bluff Limestone.

766′ 9″-903′—Greenish white, partially recrystallized, glauconitic bryozoal limestone, with poorly preserved foraminifera dominated by pelagic species.

Pullenia sp.
Cassidulina sp.
Cibicides sp.
Globigerina mexicana Cushman
Globigerina sp.
Globigerinoides index Finlay
cf. *Heronallenia pusilla* Parr

903′-904′ 8″—Brown calcareous grit. This is apparently the basal bed of the Wilson Bluff Limestone. It consists of coarse grains of limonite from the underlying sands and polished coarse subrounded quartz grains in a calcareous matrix.
Moulds of pelecypod fragments are present.

904′ 8″-927′ 3″—Brown, coarse limonitic quartz sand and gravel, with glossy iridescent grains of limonite and glauconite altering to limonite. The sample is considerably contaminated from the overlying limestone.
The boring is considered to be still in the Eocene at this depth. The name "Hampton Conglomerate" has been applied to the formation (Fairbridge, 1953, p. X1/9), which bears a lithological similarity to the South Maslin Sands of the Adelaide Basin.

927′ 3″-928′ 6″—Hard band

928′ 6″-963′ 6″—Grey-green highly glauconitic silty sand. The sample is carbonaceous and consists of medium to coarse, angular to subrounded, quartz grains with abundant irregular grains of bright green glauconite, and in lesser abundance grey quartz grains, intergrowths of glauconite and hematite, large rounded grains of opaline quartz and pyrite. A single specimen of *Haplophragmoides* sp. cf. *rugosa* Cushman and Waters and one test of an arenaceous foraminifer were recovered from the washings.

963′ 6″-968′—Greenish grey, hard, fine-grained, glauconitic sandstone.

968′-988′—Greenish grey, highly carbonaceous, glauconitic silty sandstone. Washings consist of bright green glauconite grains, silt particles, polished, fine to medium, subangular to subrounded, clear quartz grains, a few arenaceous foraminifera including *Haplophragmoides* sp., and fish remains.

988′-1016′ 8″—Greenish grey, glauconitic silty grit with bright green glauconite grains, silt particles, coarse subrounded both grey opaline and clear quartz grains with fractured surfaces, muscovite, and rarely arenaceous foraminifera: *Haplophragmoides* sp. cf. *rugosa* Cushman & Waters, *Haplophragmoides* sp., *Halophragmoides* cf. *glabra* Cushman & Waters.

1016′ 8″-1018′ 8″—Hard ferruginous greensand, with dominant pale green glauconite and subrounded quartz grains in an ironstone matrix.

1018′ 8″-1072′ 8″—Grey-green, fairly hard, silty pyritic greensand, with chlorite, muscovite and fish remains. No foraminifera were recovered.

1072′ 8″-1104′—Grey-green soft unconsolidated silty greensand, with light green irregular glauconite grains, fine to medium, angular to subrounded, clear quartz grains with both polished and etched surfaces. Fish remains are present: no foraminifera were detected.

1104′-1470′—At 1104′ there is a change in lithology and the greensands are replaced by a light grey carbonaceous mudstone with a hand band at 1365′-1365′ 6″.

1470′-1471′—Hard brown ferruginous band.

1471′-1486′—Dark grey soft mudstone.
The mudstone is carbonaceous and glauconitic with fine angular quartz grains, both dark and light green glauconite grains, pyrite, and considerable staining with green mineral. An assemblage of small arenaceous foraminifera with Upper Cretaceous affinities is present.

Haplophragmoides spp.
Haplophragmoides cf. *glabra* Cushman & Waters
Spiroplectammina cf. *semicomplanata* (Carsey)
Spiroplectammina sp.
Gaudryina sp.
Verneuilina sp.
Marssonella trochus (d'Orbigny)
Marssonella cf. *ellisorae* Cushman
Trochammina sp.

1486′-1486′ 6″—Hard band.

1486′ 6″-1523′—Dark grey mudstone, carbonaceous and glauconitic as 1471′-1486′, with a similar microfauna.

Haplophragmoides spp.
Haplophragmoides cf. *glabra* Cushman & Waters
Ammobaculites sp.
Spiroplectammina cf. *semicomplanata* (Carsey)
Spiroplectammina sp.
Dorothia spp.
Dorothia cf. *glabrata* Cushman
Trochammina spp.
Cibicides sp.

1523′-1775′—At 1523′ the boring entered grey, fine-grained, carbonaceous argillaceous sandstone.
Washings consist of fine angular quartz grains, much silty matter, iron oxide, small grains of pale green glauconite, muscovite, pyrite. The sample effervesces strongly on boiling in washing soda.
No foraminifera were detected.

1775′-1839′—Greenish grey, fine-grained sandstone.
As the previous sample, the sandstone is silty and glauconitic.

1839′-1979′—Grey sandy carbonaceous mudstone, with fine grains of pyrite and pale green glauconite. No foraminifera were observed, but radiolaria (?) *Dictyomitra* and (?) *Cenosphaera* are present.

1979′-1991′—Dark grey-brown, micaceous, carbonaceous sandstone and grit. Washings consist of angular quartz grains, botryoidal hematite, chlorite, kyanite, felspar, actinolite, pyrite, and abundant arenaceous foraminifera mostly undescribed but similar to those occurring in the Lower Cretaceous of the Great Artesian Basin in South Australia.

Involutina sp.
Haplophragmoides dickinsoni Crespin
Haplophragmoides sp.
Textularia anacoorensis Crespin
Siphotextularia sp.
Spiroplectammina spp.
Dorothia sp.
Trochammina cf. *raggatti* Crespin
Trochammina minuta Crespin
Trochammina sp.

1991′-1991′ 6″—Hard band.

1991′ 6″-2014′—Brown silty fine sandstone.
Washings consist of fine angular quartz grains, silty matter, limonite, chlorite, muscovite.

Involutina spp.
Haplophragmoides dickinsoni Crespin

Haplophragmoides spp.
Haplophragmoides chapmani Crespin
Textularia anacoorensis Crespin
Spiroplectammina sp.
Dorothia sp.
Marssonelia cf. *ozawai* Cushman
Gaudryina cf. *parallela* (Reuss)

2014'-2015'—Hard band.

2015'-2041'—Brown incoherent sandstone.
Washings of angular quartz grains, limonite-stained felspar, chlorite, muscovite.
Haplophragmoides dickinsoni Crespin
Haplophragmoides spp.
Textularia anacoorensis Crespin
Marssonella cf. *ozawai* Cushman
Trochammina cf. *raggatti* Crespin
Trochammina sp.

2041'-2049'—Sand debris from bottom of bore, apparently deepened as 2041' noted as being bottom of hole.

2049'-2101'—Grey fine laminated micaceous shale with coarse subangular quartz grains, plant fragments, and muscovite. As only a small amount of core available, sample was not washed for microscopic examination.

Correlation

From surface to 8 feet the bore was logged as passing through light loam.

Quaternary

Pleistocene: 8-30 feet

Below 8 feet the boring passed through 22 feet of Pleistocene shelly limestone typical of that overlying Wilson Bluff Limestone on the Eyre (Roe) Plain.

Tertiary

(i) Eocene *(Wilson Bluff Limestone)*: 30-903 feet

Unfortunately only one sample was kept as typical of the interval 30-508 feet. This is the Wilson Bluff Limestone of Upper Eocene age. The Limestone is glauconitic near the base which is marked by a basal grit 1 foot 8 inches thick.

(ii) Eocene *("Hampton Conglomerate")*: 904 feet 8 inches - 928 feet 3 inches

The formation name was applied by Fairbridge without definition or correlation. Correlation with Eocene sands of the Adelaide Basin is indicated mainly on lithology and on the fact that carbonaceous beds of Eocene age outcrop at Pidinga on the eastern margin of the Eucla Basin. The formation appears to be 22 feet 5 inches thick in the bore.

Cretaceous

(i) Santonian: 927 feet 3 inches - (?) 1523 feet

At 927 feet 3 inches the boring passed into highly glauconitic silty sands grading into greensands. The sediments are carbonaceous with occasional arenaceous foraminifera and fish remains indicating deposition under paralic conditions. No direct correlation is possible from the foraminifera but it is suggested that the greensands may be equivalent to the Molecap Greensand of the Gingin-Dandaragan area.

Below 1471 feet the greensands are replaced by soft mudstones with a microfauna of small arenaceous foraminifera with Upper Cretaceous affinities.

(ii) (?) Cenomanian-Albian: 1523-1979 feet

The only faunal evidence which could be obtained for purposes of correlation within this interval is the presence of *Dictyomitra* sp. and *Cenosphaera* sp. which have been recorded from the Windalia Radiolarite of the North West Division.

(iii) Aptian: 1979-2014 feet.

At 1979 feet the boring passed into carbonaceous sandstones with abundant arenaceous foraminifera typical of Lower Cretaceous (Aptian) sediments of the Roma Series in the Great Artesian Basin in South Australia.

The whole of the Cretaceous sequence is paralic, all sediments being carbonaceous and mostly glauconitic.

Palynological study of the core of this bore should be undertaken to confirm the correlations based on arenaceous foraminifera and to establish the age of the sediments which did not appear to contain any foraminifera, particularly in the intervals 1104-1470 feet, 1523-1979 feet, 2049-2101 feet.

R. W. Fairbridge (1953, p. X1/9) gave the name "Madura Shale" without definition and contrary to the Australian Code of Stratigraphic Nomenclature to a formation claimed to underlie "the Eucla Limestone (and Hampton Conglomerate where present)" and to overlie the Loongana Conglomerate (1953, p. S/9). It is uncertain to which portion of the Madura Bore this is intended to apply. The age of the "Madura Shale" is stated on p. X/9 to be Tertiary, on p. X1/9 to be Cretaceous.

W.A. Government Survey Bore No. 2.
30 miles north of Madura
410 feet above sea level
Reference 4625. Drilled P.W.D.

0'-6'—No core.

6'-30'—Cream dense limestone with molluscan moulds and the foraminifera *Marginopora vertebralis* Blainville and abundant miliolidae.
This is Nullarbor Limestone (Lower Miocene).

30'-34'—No sample available.

34'-72'—Cream partially recrystallized limestone with *Cibicides pseudoungerianus* Cushman, *Gypsina howchini* Chapman, *Amphistegina lessoni* d'Orbigny, *Operculina* sp., *Nonion* sp.

72'-75'—Hard white somewhat chalky limestone.

75'-104'—Cream, partially recrystallized limestone with essentially the same microfauna as 34'-72', poorly preserved but including *Operculina* and *Amphistegina*.

104'-130'—White limestone.

130'-175'—White limestone.

175'-185'—Cream hard recrystallized limestone with *Guttulina* sp. *Cibicides pseudoungerianus* Cushman, *Notorotalia* cf. *howchini* (Chapman, Parr & Collins), *Amphistegina* sp. and a shark's tooth.

185'-200'—Cream limestone.

200'-216'—Hard cream limestone.

216'-230'—Cream recrystallized limestone with a poorly preserved coral.

230'-246'—Cream soft limestone (small sample).

246'-260'—Cream soft limestone (small sample).

260'-284'—Cream recrystallized limestone as 216'-230' with a few bryozoa and foraminifera and an occasional glauconite grain. Diagenesis has proceeded too far for identification of the fauna.

284'-300'—As previous sample.

300'-318'—No core available.

318'-326'—Pink recrystallized limestone with a few poorly preserved foraminifera and bryozoa.

216'-340'—No core available.

340'-360'—Cream recrystallized limestone with echinoid spines, a few foraminifera too poorly preserved for identification. One species appears to be close to or identical with *Cibicides pseudoconvexus* Parr.

360'-410'—No core available.

410'-412'—Cream recrystallized bryozoal limestone with poorly preserved small foraminifera with a Wilson Bluff Limestone aspect.

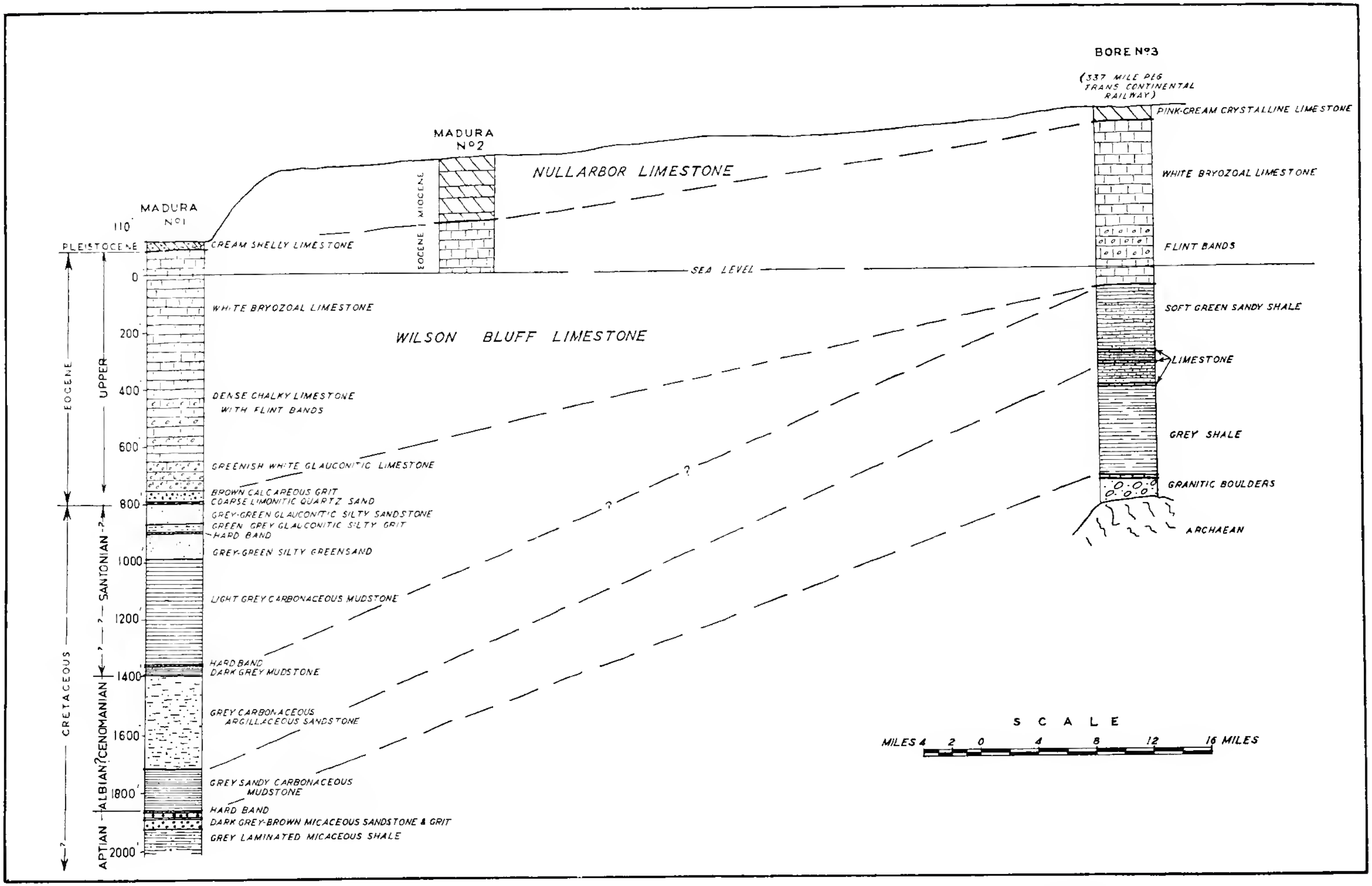

Fig 5.—Section from Madura to 337-mile peg, Trans-Continental Railway, Western Australia.

Correlation

The poor state of preservation of most of the microfossils and the small size of the samples renders it difficult to distinguish clearly the boundary between the Nullabor Limestone which was entered at 6 feet depth, and the Wilson Bluff Limestone in which the boring ceased at 412 feet. The following correlation is therefore tentative only.

0-216 feet *Nullarbor Limestone* (Lower Miocene)—Samples from 34-185 feet carry a microfauna of Lower Miocene age. From 6-34 feet the core is typical of the upper portion of the Nullarbor Limestone while the fauna of the less dense limestone from 34-185 feet with "Batesfordian" affinities occurs near the base of the Nullarbor Limestone elsewhere.

216-318 feet—There is insufficient information available to determine the age of the limestone in this interval. The relatively poor fauna may indicate either transitional sediments of late Oligocene-early Miocene ("Longfordian") age of the weathered upper portion of the Wilson Bluff Limestone.

318-412 feet *Wilson Bluff Limstone* (*Upper Eocene*)—Although the faunas are poor, the lithology and condition of preservation of the microfauna permits determination of the Wilson Bluff Limestone below 318 feet.

W.A. Government Survey Exploratory Bore No. 3, 337 mile peg Trans-continental Railway, 28 miles west of Loongana

Reference 11229. Drilled P.W.D., 1907

? Surface—Reference 1 1243 1-8

1. Pink hard limestone with numerous corals, bryozoa and molluscan moulds, including:
   Corals: cf. *Placotrochus* sp.
   Pelecypoda: Fulvia sp. cf. *tenuicostata* (Lamarck)
2. Weathered recrystallized limestone with corals (*Placotrochus* etc.), bryozoa, molluscan moulds.

3-8. Selected specimens from the same limestone. These are all samples of weathered Nullarbor Limestone (Lower Miocene), presumably outcropping near the bore.

0′-3′—Surface soil.
3′-50′—Dense pinkish cream crystalline limestone with abundant miliolidae and *Marginopora vertebralis* Blainville: Nullarbor Limestone.
50′-65′—No sample: logged as "soft limestone."
65′-67′—White recalcified bryozoal limestone with *Cibicides umbonifer* (?) Parr Although the faunal evidence is slender, the appearance of the sample suggested that the boring has here entered the Wilson Bluff Limestone (Upper Eocene).
67′-130′—Pink-cream bryozoal limestone.
130′-149′—White bryozoal limestone.
149′-413′—White bryozoal limestone (Wilson Bluff Limestone).
413′-478′—Wilson Bluff Limestone, with flints.
478′-530′—Dense white bryozoal limestone.
530′-630′—No sample logged as "soft limestone with flints."
630′-813′—No sample (logged as soft green sandy shale).
813′-816′—"Hard band" (no sample).
816′-857—"Sandy shale with hard bands" (no sample).
857′-860′—"Hard bands of shale" (no sample).
860′-890′—"Soft sandy shale."
(?) Sample of greenish grey sandstone with fine angular quartz grains, pale green irregular grains of glauconite.
892′-905′—"Soft sandy shale."
905′-910′—Hard greenish grey limestone.
910′-1270′—Grey carbonaceous mudstone, leaving little residue on washing. Washings consist of fine angular quartz grains, pale green irregular glauconite grains, muscovite, pyrite, with the radiolaria (?) *Lithocyclia* sp., (?) *Dictyomitra* sp. and small impoverished foraminifera *Trochammina* sp, *Siphotextularia* sp.
1270′-1344′—"Fine and coarse sands."
Sample 1290′-1293′ is grey limestone, 1293′-1344′ grey granite.
1344′-1370′—"Decomposed granite."
1370′-1372′—Gneissic Archaean basement

Correlation

The loss of labels on some of the deeper core samples has made it difficult to relate these samples to the bore log.

Tertiary limestones

(i) Nullarbor Limestone 3-(?)50 feet

Below surface soil and apparently outcropping in the vicinity of the bore is the Nullarbor Limestone of Lower Miocene age.

(ii) Wilson Bluff Limestone (?) 50-630 feet

At 65 feet, possibly at 50 feet, the boring entered the Upper Eocene Wilson Bluff Limestone of a maximum thickness of 580 feet in the Bore.

(iii) Mesozoic

(a) Albian (in part) 630-1270 feet

The material still available from depths below 630 and 910 feet is insufficient to determine the age of the shale with limestone bands apparently penetrated in this interval. If, as seems possible, the two species recorded by Maitland (1915, p. 13) *Aucella hughendenensis* and *Maccoyella corbiensis*, were recovered here, an Upper Albian age is indicated.

(b) (?) Albian

The name "Loongana Conglomerate" was introduced by Fairbridge (1953, p. X/0) without redescription of the core for the "fine and coarse sand with hard bands and granite boulders" between 1260 and 1314 feet. Only 2 samples are now available, one of which is calcareous and the other granite. There is no evidence to suggest the presence of Aptian sediments.

(iv) Archaean basement.

At 1370 feet the boring entered highly altered basement rock with a calcareous matrix.

W.A. Government Survey, 245 Mile Bore, Transcontinental Railway

Reference 1,319

4 labelled samples

0′-4′—Yellow-brown calcareous clay.
4′-42′—Hard travertine.
42′-96′—Fragments of cream-coloured, hard, dense fossiliferous limestone mixed with surface soil.
The limestone carries abundant miliolidae, together with *Marginopora vertebralis* Blainville.
This is Nullarbor Limestone, of Lower Miocene age.
96′-250′—Cream-coloured, chalky crystalline limestone with some glauconite. Organic remains are poorly preserved but bryozoa, echinoid spines, fragments of brachiopod shells and the foraminifera *Spirillina* sp., cf. *Stomatorbina torrei* (Cushman & Bermudez), *Cibicides umbonifer* Parr, *Cibicides vortex* Dorreen, *Cibicides* sp., *Asterigerina adelaidensis* (Howchin), *Crespinella* sp. B may be recognized. This is Wilson Bluff Limestone, of Upper Eocene age.

Murrawijinnie Cave

Reference 1/1244

Specimen
No.

9 Cast of *Polinices* sp. in crystalline limestone (Nullarbor Limestone).
10 Cast of volute indet.
11 Cast of venerid indet.
12 Distorted cast of gastropod indet.
13 Cast of gastropod indet.
14 Cast of gastropod indet.
15 Recrystallized bryozoal limestone with fragment of *Chlamys*.
16 Piece of a stalactite.

Specimens 9-15 have been collected from the Nullarbor Limestone.

Murrawijinnie Bore (80-100 ft depth in shaft)

Reference 1/1245

17 Nullarbor Limestone with *Chlamys eyrei* (Tate) and cast of probably *Antigona* sp.
18 Weathered recrystallized cream bryozoal limestone (Nullarbor Limestone) and *Chlamys eyrei* (Tate).
19 Nullarbor Limestone with *Glycymeris* sp., volute indet, and *Marginopora vertebralis* Blainville.
20 Cast of *Alcithoe (Cottonia)* sp., common at base of Nullarbor Limestone.
21 Limestone with *Vasticardium* sp. and *Marginopora vertebralis* Blainville.
22 No sample.
23 Recalcified limestone, with venerid indet.
24 Recalcified limestone with venerid indet and *Dentalium* sp.
25 Recalcified limestone with gastropod indet.
26 Recalcified limestone with fragment of *Antigona* sp., pelecypod indet, bryozoa, mould of (?) *Placotrochus*.

Specimens 17-26 are from the Nullarbor Limestone.

Delisser's Bore (at 147 ft)

Reference 1/1246

27 Cast of large gastropod (?) *Turbo* sp.
28 Portion of *Nautilus* sp. cf. *geelongensis* Foord.

These belong to the Nullarbor Limestone.

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16.—An Unusual Adularia from the Billeranga Hills, Western Australia

By J. E. Glover*

Manuscript accepted—17th June, 1958

K-feldspar phenocrysts in trachyte from the Billeranga Hills (Western Australia) have Carlsbad and Manebach twins, and exhibit a range in optical properties apparently caused by partial inversion to microcline. Unusually slow cooling of the magma, perhaps aided by other effects, may be responsible.

Introduction

The Billeranga Hills are near the western edge of the Precambrian shield of Western Australia, about 225 miles by road north of Perth, and about 30 miles by road east of Mingenew. The sequence consists of unmetamorphosed, interbedded flows and sandstones of probable Proterozoic age, but has not, so far, been investigated in detail.

Petrography

The K-feldspar described below occurs in an iron-stained trachyte specimen† from a flow near the bottom of the sequence. The rock is red-brown and amygdaloidal with phenocrysts of light grey K-feldspar, generally about 0.6 mm long, in a red-brown groundmass. The groundmass contains numerous dendritic aggregates of black iron ore and is so impregnated with limonite as to be locally opaque. Translucent patches are optically anisotropic, with low birefringence and irregular, wavy extinction, suggestive of incompletely crystallized feldspar. Feldspar phenocrysts range in shape from almost euhedral to anhedral, and some of the latter may have been partly resorbed. The grains contain numerous inclusions of red-brown and black iron ore, some aligned parallel or nearly parallel to (010) and (001) but most without apparent preferred orientation. The amygdales are irregularly shaped and are mostly about 0.5 mm in diameter, although some are considerably larger. They generally consist of quartz with undulose extinction, and are all heavily charged with iron ore inclusions. Some amygdales also contain pale yellow fibrous aggregates of a mineral the relief and birefringence of which are slightly greater than quartz. The fibres have straight or nearly straight extinction, are length-slow, without discernible pleochroism, and are commonly radiating. This mineral, which also partly replaces a few feldspar grains, is probably deuteric, and may be a variety of chlorite.

Approximate composition of the rock, from visual estimation, is:

	%
Groundmass	46
K-feldspar	40
Quartz	8
(?) Chlorite	6

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† Specimen No. 36923, Geology Department, University of Western Australia.

Chemical Composition of the Feldspar

Concentration of iron ore inclusions is generally lower in the feldspar than in the quartz amygdales and groundmass, enabling a preliminary gravity separation of feldspar from the crushed rock in bromoform. Magnetic separation in the Franz isodynamic separator eliminated remaining fragments of groundmass, feldspar with a high concentration of iron ore inclusions, and most of the quartz. The residue consisted of feldspar and a little quartz, both with a few iron ore inclusions. A count of 1,000 grains under the microscope indicated a composition for the residue of 97% feldspar, 3% quartz. Partial analysis of the residue with the Lange flame-photometer showed K_2O 16.18%, Na_2O 0.36%, CaO 0.01%‡. The feldspar is, therefore, highly potassic and contains about 16.7% K_2O, 0.4% Na_2O and 0.01% CaO.

Measurement Technique

Measurements of the feldspar were made with a four-axis Universal Stage, and were plotted on a Schmidt (equal-area) net. Where possible, only grains with both optic axes accessible were selected. A procedure based on the direct method outlined by Fairbairn and Podolski (1951), and designed to eliminate instrument errors, was adopted. Each recorded value of 2V represents the average of eight direct measurements, and is considered reproducible to within 1°, and generally to within ½°. The average of eight measurements was recorded for each accessible principal optical direction, and the inner stage was rotated through approximately 180° after each measurement. The same technique was adopted when measuring and recording positions of poles of composition and cleavage planes. All measurements were made with white light, as high intensity was necessary.

The two accessible optical directions in grains selected for measurement are Y and Z. Where both optic axes are measured directly, X, midway between them, can be plotted on the projection, and need not be located by construction from Y and Z. This provides a useful check on the overall precision of measurement and plotting, for X and Z should lie 90° apart.

Morphology and Optics of the Feldspar

Notable features of the morphology and optics of the feldspar are listed below, and their probable significance is discussed later.

(i).—Some fairly euhedral grains are present, but others have irregular outlines suggestive of resorption.

‡ Analyst, F. Billing, Dept. of Geology, University of Western Australia.

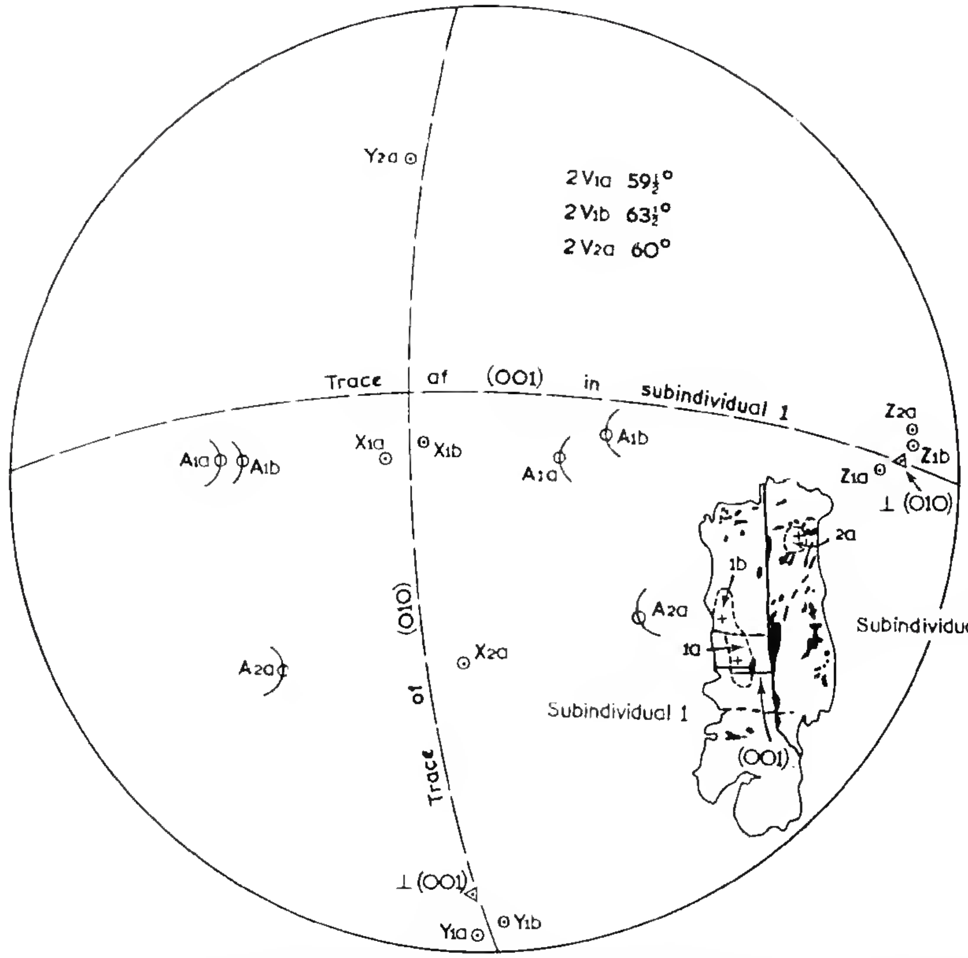

Fig. 1.—Equal area projection (lower hemisphere) of optical and crystallographic data from an adularia grain with Carlsbad twins. Points in the grain at which measurements of 2V and the directions of Y and Z were made shown thus +. The points are enclosed by dashed lines indicating the extent of the area in which extinction is fairly constant.

(ii).—Most grains are twinned on the Carlsbad law, but some are twinned on the Manebach law.

(iii).—No subindividual has completely uniform extinction. Carlsbad and Manebach twin laws can be established from measurements of the mean extinction positions for each subindividual.

(iv).—Patchy, irregular extinction is caused by different orientation of the optical indicatrix in different areas of the same subindividual. The maximum observed variation of a principal optical direction in two adjacent areas of one subindividual is 13° (see $\mathbf{X}_{2a}$ and $\mathbf{X}_{2b}$ in Fig. 2).

(v).—In some places there are minute, poorly defined, intersecting lamellae, parallel in a general way to (010) and (001). They suggest incipient albite and pericline twins, and are generally confined to small, irregularly shaped, isolated patches in the grains.

(vi).—2Vα may range considerably in different areas of the same grain, the maximum observed difference being 12½°. The overall range of 2Vα in ten measured grains is 15° (52½° to 67½°).

(vii).—Cleavages and twin composition planes are bent and distorted in some grains by up to 5°.

(viii).—Areas of uniform extinction in the grains are commonly too small to measure 2V precisely, or to establish the orientation of the indicatrix. Measurements were confined to patches in which extinction appeared uniform over a sufficiently large area for consistently reproducible results.

Twin Laws

Apart from apparent patches of incipient albite and pericline twins, grains contain only two subindividuals. These latter twins fall into two categories, parallel and normal.

Parallel twins

Although any one principal optical direction varies in different areas of a subindividual, a mean position for it on the projection can be assumed. Approximate location of the twinning axis from intersection of great circles joining mean positions of $\mathbf{X}_1\mathbf{X}_2$, $\mathbf{Y}_1\mathbf{Y}_2$ and $\mathbf{Z}_1\mathbf{Z}_2$ is possible. In parallel twins the triangle of error, even where large, is generally close enough to the trace of the twin composition plane to prevent ambiguity and to demonstrate parallelism. In such twins, the mean positions of $\mathbf{X}_1$ and $\mathbf{X}_2$ are about 40° apart, and displacement of cross cleavages in the two subindividuals is about 50°. The cross cleavage (001) and composition plane (010) are identified by proximity of their poles to principal optical directions. The above features identify the Carlsbad law (see Fig. 1).

Normal twins

The twin axis, with its approximate position located as described above, is generally sufficiently close to the normal to the twin composition plane to prevent ambiguity. In these twins, the mean positions of $\mathbf{X}_1$ and $\mathbf{X}_2$ are about 14° apart, and the twin composition plane is (001). (010)

cleavages are parallel in both subindividuals, as are (001) cleavages. Cleavages are readily identified by proximity of their poles to principal optical directions, and by their relative development—(001) perfect, (010) distinct. The above features identify the Manebach law (see Fig. 2).

In practice, the perfect (001) cleavage parallel to the twin composition plane in Manebach twins generally allows their immediate distinction from Carlsbad twins, which have the less well-developed (010) cleavage parallel to their twin composition plane.

Nomenclature

The optic plane of the K-feldspar described above is normal or nearly normal to (010) and $2V\alpha$ ranges from $52\frac{1}{2}°$ to $67\frac{1}{2}°$. According to the modification of Spencer's optical classification set forth by Chaisson (1950, p. 538), the feldspar is best called adularia. However, the Z direction, which in optically monoclinic adularia should coincide with the normal to (010) (the *b* crystallographic axis), is not constant everywhere in the same grain. Distortion of some grains, evident from bent cleavages, cannot fully account for all variations in orientation of the indicatrix, for many adjacent areas with notably different optical orientation are traversed by clearly defined, continuous and undistorted cleavage. In such areas, observed differences in optics are probably due to varying degrees of departure from the ideal monoclinic symmetry, that is, to varying degrees of triclinicity. The optics and chemical composition of the mineral thus indicate that it lies in the region of intermediate microclines outlined by MacKenzie and Smith (1956, Fig. 1, p. 406).

Discussion

Existence of high- and low-temperature forms of alkali feldspar is now well recognised. Following Barth's conception of polymorphism in K-feldspar (Barth, 1934), Laves (1950), postulated an order-disorder relationship in the location of the Al and Si atoms between high- and low-temperature forms of K-feldspar. In sanidine, the monoclinic modification stable at high temperature, Al and Si are disordered: in microcline, the triclinic modification stable at low temperature, Al and Si are ordered. The concept is expanded in later papers Goldsmith and Laves, (1954*a*, 1954*b*).

Departures from the monoclinic optics hitherto generally assumed for adularia have long been recorded, and have been described recently from optical work by Köhler (1948) and Chaisson (1950), and from X-ray work by Laves (1950) and Goldsmith and Laves (1954*a*, 1954*b*). The last-mentioned assume a continuous range in triclinicity from 0 in monoclinic K-feldspar to 1 in "maximum" microcline. This range is a function of Al-Si order-disorder, and feldspars with intermediate triclinicity are stated to be

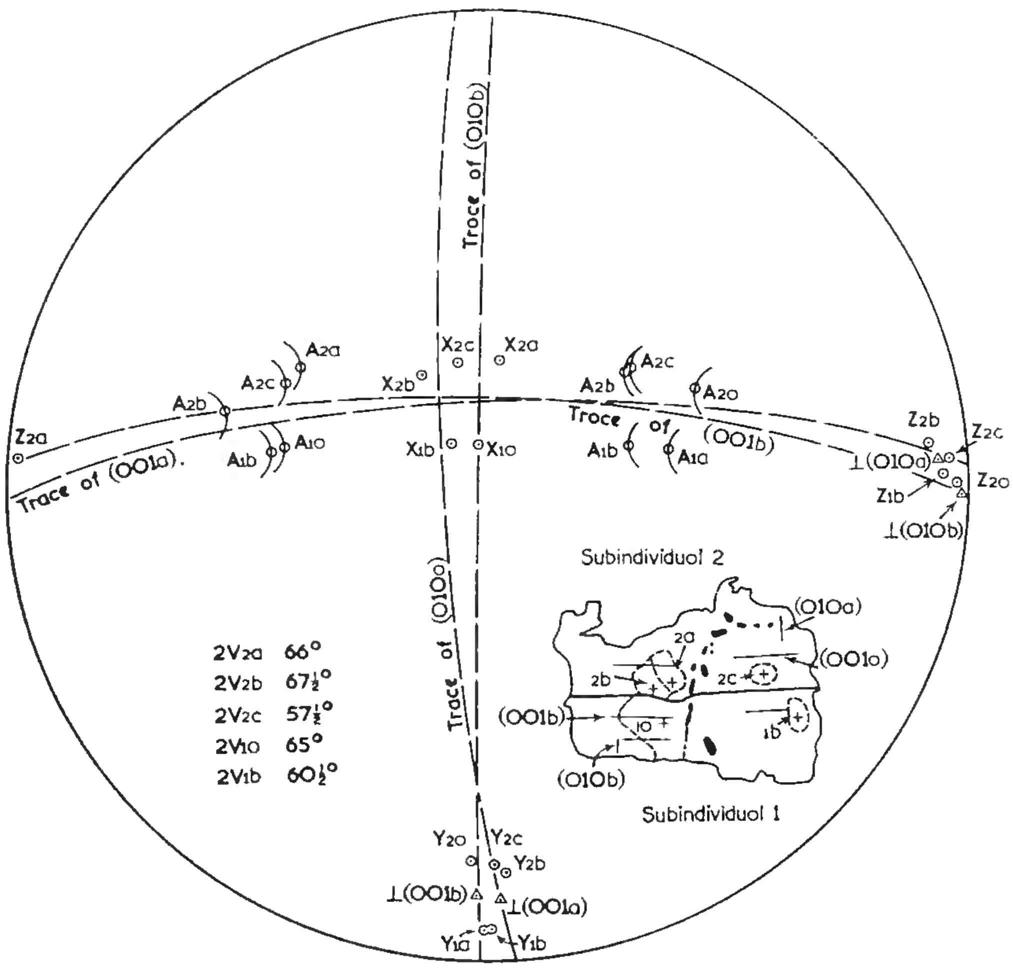

Fig. 2.—Equal area projection (lower hemisphere) of optical and crystallographic data from an adularia grain with Manebach twins. Points in the grain at which measurements of 2V and the directions of Y and Z were made shown thus ·+. The points are enclosed by dashed lines indicating the extent of the area in which extinction is fairly constant.

not uncommon. They have observed large variations in triclinicity in the same "crystal," and assume from earlier work (Laves 1950) that the characteristic combination of albite-pericline twinning in microcline indicates inversion from an original monoclinic crystal. Orthoclase, although apparently optically monoclinic, is considered by Goldsmith and Laves to consist of submicroscopic units, with all possible degrees of Al-Si order, and it cannot be assigned a well-defined stability field.

Transformation of the stable or metastable high-temperature forms of K-feldspar to the highly ordered triclinic form is very sluggish and, unlike the reverse process, has not so far been observed in the laboratory. General restriction of microcline to granitic rocks (whether conceived to be essentially magmatic or essentially metamorphic in origin) is probably due to the long time available for transformation under equilibrium conditions, during slow cooling at great depths. Virtual absence of microcline from volcanic rocks is probably due to rapid, commonly spasmodic cooling at relatively shallow depths, quenching the stable high temperature monoclinic modification (sanidine) and the metastable optically monoclinic modifications (orthoclases). However, with unusually slow cooling, perhaps accompanied by favourable, as yet unknown physico-chemical conditions, partial inversion to the more ordered form in some volcanic rocks is likely. Grains showing such inversion are probably best sought in rocks such as trachytes, which are normally differentiates, and are thus likely to be products of slow cooling in the magmatic chamber.

Conclusions

The optics of adularia from trachyte in the Billeranga Hills are thought to have arisen from processes set out above. If so, the distortion in some grains, revealed by bent cleavage and composition planes, is likely to have resulted from internal strains caused by numerous centres of inversion. The hypothesis is strengthened by the presence of small patches of poorly developed cross-hatching in many grains. Origin of the irregular boundaries of some grains is not certain: they may have been caused by resorption during release in pressure on extrusion of the lava.

In view of the probable factors causing their inversion detailed optical work on naturally occurring K-feldspars may eventually help in unravelling the cooling history of extrusive rocks in which they are found, even though the value of K-feldspars as absolute indicators of geologic temperature is now suspect.

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Memorial

Harry Bowley (1883-1958)

Harry Bowley, F.A.C.I., ex-Director of the Government Chemical Laboratories, died on Sunday, March 30th, 1958, at the age of 75. He was born at Crystal Brook in South Australia in 1883 and came to Western Australia at the age of 13.

He began his long Government service when he was appointed a junior clerk in the Geological Survey Branch of the Mines Department in 1898. In 1899 his professional career commenced with his appointment as cadet and thereafter he progressed steadily in his chosen profession; laboratory assistant, assistant assayer, assistant mineralogist and assayer.

Early in 1922 the Geological Survey Laboratory and the Government Analysis Laboratory were amalgamated to form the Government Chemical Laboratories and in 1926 Mr. Bowley was appointed Senior Mineralogist and Chemist, and in 1939 he was appointed Government Mineralogist and Analyst.

Bowley was mainly responsible for the conception, design and equipment of the modern laboratories in Adelaide Terrace, which were completed in 1943. In 1946, following a general re-organisation, he was appointed Director of the Government Chemical Laboratories, a position which he held until his retirement.

In his official capacity Bowley acted on many important committees associated with Water Supply, Public Health and Mineral Development. He was a member of the special committees responsible for the war-time development and management of the Chandler Alunite Works and the Charcoal Iron Industry at Wundowie.

Bowley was a foundation member of the Chemical Society of Western Australia which later became the Western Australian Branch of the Australian Chemical Institute. He was appointed a Fellow of the Institute in 1929, served a term as its General President, and was a signatory to the petition for the granting of a Royal Charter (to the Institute).

In recognition of his services to the chemical profession he received the Institute's gold medal in 1937, and for many years acted on the Fellowship Panel of the State Branch of the Institute.

Bowley served a long term as Government Appointee on the State Advisory Committee of the C.S.I.R O. and was one of the chief movers responsible for the formation of the National Association of Testing Authorities (N.A.T.A.). He served on the committee of this body until his death.

During his long association with the Royal Society of Western Australia he occupied the positions of council member, Honorary Treasurer, Vice President and President.

In recognition of his services he was elected an Honorary Life Member of the Society in 1953. His Presidential Address entitled "The Ceramic Resources of Western Australia" was a valuable contribution to knowledge dealing as it did with many important clay and mineral deposits useful to the State's industrial development.

In addition to his scientific interests Bowley was a very keen Freemason and introduced into his masonic activities the same drive and enthusiasm which characterised his professional career.

Bowley was not a man to suffer fools gladly, but he earned the respect of his colleagues and the esteem of a wide circle of friends. In the words of one of his close associates "His manner in discussions, however forceful, was such that he earned the very deep respect of those who worked with him, and he will be long remembered as a capable colleague and a warm friend."

C. F. H. JENKINS.

Memorial

Edward de Courcy Clarke (1880-1956)

Emeritus Professor Edward de Courcy Clarke, formerly Professor of Geology in the University of Western Australia, died at the Kalgoorlie Hospital on Friday, 30th November, 1956. He was a highly esteemed member of the Royal Society of Western Australia, having served this Society faithfully almost continuously during the period 1919-1949 when he was associated with the University of Western Australia. He was President of the Society in the years 1922-3 and 1935-6, Honorary Editor 1923-6, and Member of Council during the periods 1919-22, 1932-34, 1936-37 and 1941-44. Throughout the period of his association with the Society he was constantly consulted as the Society's main referee on geological matters. The Society recognized

his valued work for the Society in advancing interest in science in Western Australia and for his original contributions to Geology by awarding him its highest honour, the Kelvin Medal, in 1941.

Clarke was born at Waimate, New Zealand, on the 10th November, 1880, and was educated at the High School, Napier, and at University College, Auckland. On completing his University studies in 1901 he was appointed Science Master at Auckland Grammar School, a position which he occupied till 1907. During this time his main interest was in palaeobotany. In 1907 he became a field geologist with the Geological Survey of New Zealand and held this position until he resigned in February, 1910, to take up academic work as a Demonstrator in Geology and Biology at University College, Auckland

In 1912 he received an appointment as field geologist with the Geological Survey of Western Australia and spent the remainder of his professional career in this State. He was associated with the Geological Survey of Western Australia from 1912 to 1920 when he was appointed Lecturer-in-charge of the Department of Geology at the University of Western Australia. He remained with the University of Western Australia until he retired from professional work in 1948, being given the title of Associate Professor in 1928, and Professor of Geology in 1930. During this time his main interest was in the Precambrian formations which form so much of the southern half of the State and this interest is evidenced by his Presidential Addresses to the Royal Society of Western Australia in 1923 and to the Geological Section of the Australian and New Zealand Association for the Advancement of Science in 1930. In addition he accomplished much original work on physiographic problems, chiefly in the South-West, but also on the broader aspects of physiography in Western Australia.

During his association with the University of Western Australia he carried out much original work and was a source of inspiration to a large school of younger geologists who are today contributing much to the development of the natural resources of Australia. Above all he insisted that training in actual field survey methods, and not simply inspectional field work, was an indispensable requisite in the training of geologists. The value of this type of training is seen in the high respect that his past students enjoy in many parts of Australia and overseas.

He was author or co-author of thirty-six bulletins and original papers and four textbooks of Geology, and his work has been recognized by the awards to him, in 1941, of the Kelvin Medal of the Royal Society of Western Australia, and, in 1954, of the Clarke Medal of the Royal Society of New South Wales.

Professor Clarke was a man of simple tastes and one who never sought publicity or acknowledgment of his work. To him the student was of the first importance, and, outstanding as his published contributions to geological science are, his greatest contribution was in the inspiration he yielded to his students.

REX T. PRIDER.

Memorial

James C. Hood (1896-1956)

It is with the deepest regret that we have to record the death of Mr. J. C. Hood on May 20th, 1956, at the age of 60 years. Born at Oban, Scotland, the late Mr. Hood received some of his early education in London but came to Western Australia with his parents at an early age.

In April, 1914, Mr. Hood was appointed a Temporary Junior Analyst in the Explosives and Analytical Branch of the Mines Department and after a course of study at the Perth Technical College, qualified as an analyst. In May, 1917, he was selected as one of the second group of chemists to go to England for work with the Ministry of Munitions and worked in various factories. For conspicuous service and an act of gallantry during an accident at one of these factories he was awarded the O.B.E.

Returning to Australia in 1919 Mr. Hood resumed duties in the Laboratories as an Assistant Analyst and his record is one of steady progress in his chosen profession. Chemist and Analyst 1920, Chemist 1941, Acting Supervising Chemist and Toxicologist 1943, and confirmed in this appointment in 1945, Deputy Government Analyst in 1946, culminating in his appointment in 1955 to the most senior position in his chosen field, Director of the Government Chemical Laboratories. He was elected an Associate of the Australian Chemical Institute in 1919 and a Fellow in 1952.

He was an active member of this Institute, having served several years as a Committee member and at the time of his death was Vice-President (Acting President) of the W.A. Branch. He was a member of the Royal Society for many years, was a member of Council and Honorary Auditor.

Almost all of Mr. Hood's service was in the Food, Drugs and Toxicology Division of the Government Laboratories and he was an acknowledged authority in these fields. He was essentially of a practical turn of mind, a skilled constructor of apparatus and manipulator. His broad and detailed knowledge of chemistry, particularly in relation to food, drugs and toxicology was invaluable and was always at the disposal of others. His passing was a sad loss to chemistry in this State and to his colleagues.

L. W. SAMUEL.

INSTRUCTIONS TO AUTHORS

Papers may be submitted to the Society in accordance with Rules and Regulations 38 to 41 inclusive (see below). They should be addressed to *The Honorary Secretary, Royal Society of Western Australia, Gledden Building, Perth.*

Authors are solely responsible for the factual accuracy and for any opinion expressed in their papers. They are particularly requested to verify references. Alterations to MSS. submitted to the printer will be allowed only under exceptional circumstances, and no changes will be permitted after galley-proof stage.

In the preparation of MSS. authors are required to follow the C.S.I.R.O., *Guide to Authors* (C.S.I.R.O., Melbourne, 1953), except that papers longer than 10,000 words (30 foolscap pages of pica type, with 6 inch lines 40 to the page) will not normally be accepted.

Authors may be required to meet half the cost of preparation of the blocks of diagrams and illustrations.

Authors shall receive a total of 30 reprints free of charge. Further reprints may be ordered at cost, provided that such orders are submitted with the MS.

RULES AND REGULATIONS

38. Every paper intended to be read before the Society or to be published in the Society's Journal must be sent to the Secretaries at least seven days before the date of the next ensuing Council meeting, to be laid before the Council. It will be the duty of the Council to decide whether such contribution shall be accepted, and if so, whether it shall be read in full, in abstract, or taken as read. All papers accepted for publication must be read or otherwise communicated at an ordinary meeting prior to publication.

39. A Publications Committee, appointed by the Council, shall recommend to the Council whether a paper presented to the Society shall be published in the Society's Journal. The Publications Committee may obtain an opinion from any person it may select on the suitability of any paper for publication.

40. Publication in the Society's Journal shall only be available to *(a)* Ordinary Members, *(b)* Honorary Members, *(c)* Non-members resident outside Western Australia, who must communicate the paper through an Ordinary or Honorary Member. No paper shall be accepted from a Non-member resident in Western Australia.

41. The original copy of every paper accepted for publication by the Society, with its illustrations, shall become the property of the Society, unless stipulation is made to the contrary, and authors shall not be at liberty to publish their communicated papers elsewhere prior to their appearance in the publications of the Society unless permission for so doing is given by the Society, or unless the Society fails to publish the paper in the Journal of the year in which it is read or otherwise communicated, or of the succeeding year.

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